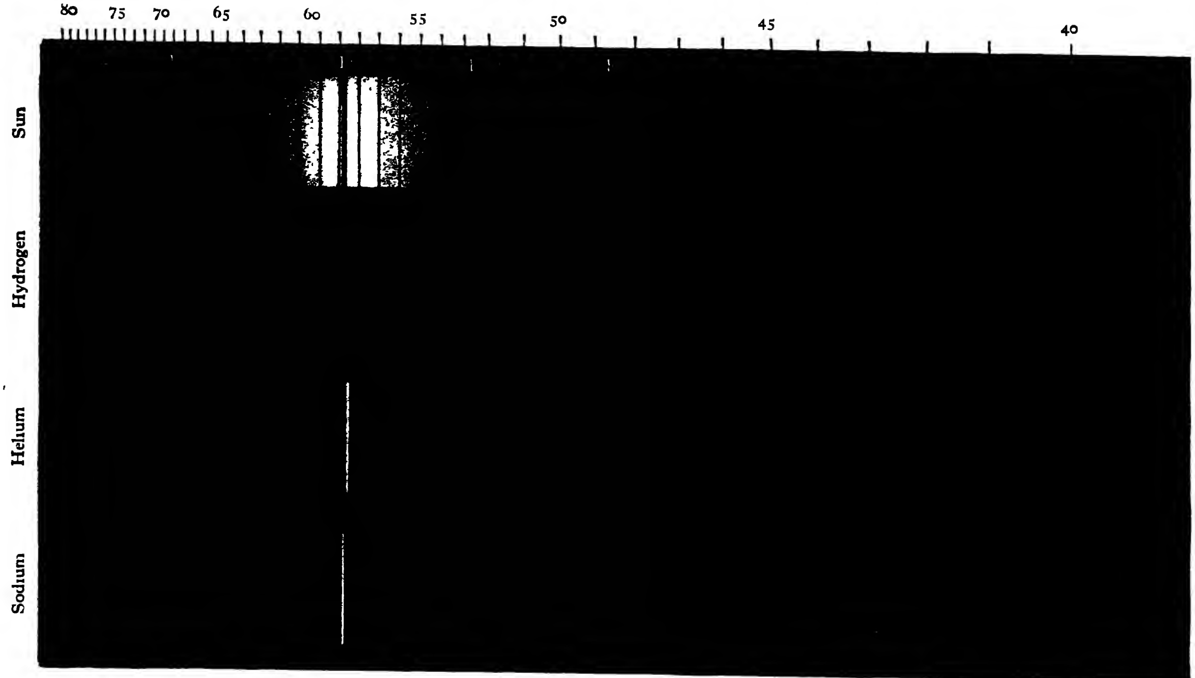
EVERYDAY SCIENCE



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Frontispiece

THE SPECTRA OF THE SUN, HYDROGEN, HELIUM AND SODIUM

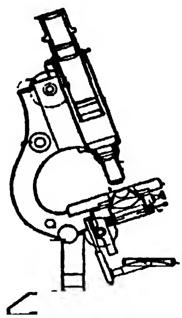
Characteristic absorption lines are shown in the sun spectrum, and also the corresponding bright-line spectra of hydrogen, helium and sodium See page 127 The scale numbers give the wave-lengths in millionths of a centimetre.

EVERYDAY SCIENCE

BY

CYRIL HALL

Author of "The Sea and its Wonders" "Treasures of the Earth" &c.



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PREFACE

The following pages are intended as an easy introduction to physical science. They try to explain for young readers how our knowledge of the properties of matter makes life more interesting and exciting as well as richer and more comfortable. My hope is that the book may make plain the value of scientific method in approaching any of the things that interest them individually.

Nearly all the countless hows and whys that pop in and out of our heads bring us sooner or later face to face with science. These chapters seek to answer some of the more ordinary hows and whys. I should like to think that they will provoke far more questions than they can answer, thereby driving the inquisitive to stiffer, solider books of serious science. It is strange how many young people still look on science as a rather terrifying bogey best left undisturbed in the difficult, dry-as-dust books where they suppose its home to be. But science is not a bit like that really. It is no bogey, but the splendid living force of adventurous discovery—a force vital and alert, radiant with happiness. The true home of science is in our own minds; because, for almost every question that comes to us, science

both puts us in the way of asking and of finding the answer as well.

I have had much help from my wife. And I am very grateful to my friend Mr. Kenneth Dickson for his kindness in reading the proofs of Chapters XIV to XVII.

CYRIL HALL.

WOOTTON, NEW FOREST

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EVERYDAY SCIENCE

CHAPTER I

A Journey Begins

" Morning," said the Funny Old Chap.

" Good morning," said Ken, making room on the seat beside him.

They usually met on the 8.30 bus, Ken on his way to school, the Funny Old Chap on his way to whatever work kept him busy all day. Sometimes they only exchanged nods and smiles, sometimes a few words passed as one or other went down the gangway, because they got on at different stages, and the bus was generally full. Ken was always glad when, as on this particular morning, they were able to sit together. The Old Chap was very friendly and jolly, with a laugh that sometimes came out as a roar that made the other passengers turn and grin, and sometimes as a low chuckle that rolled up from somewhere deep down in his inside. No one can help liking that kind of old chap. Besides, Ken had found out that they had many interests in common. They both liked the country; they both liked birds and butterflies, they both liked horses and hedgehogs, and books and boats.

" Beautiful day! Beautiful day!" said the Old Chap.

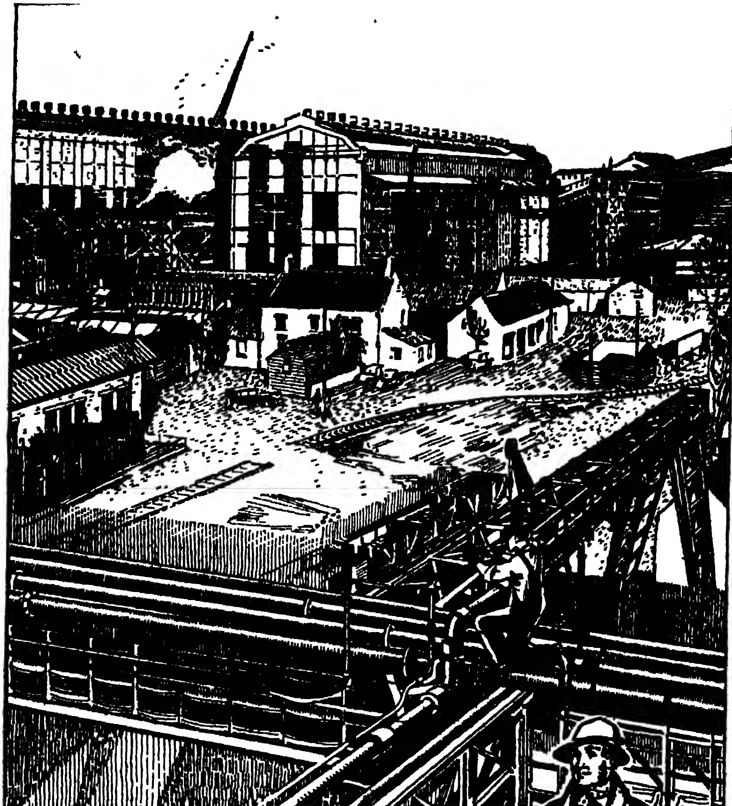
"I'll be bound you're not keen on lessons to-day. There's something in the air, a day like this, that makes us lads go all cock-a-whoop and willaboo, if you take my meaning. That's how you feel, I'll be bound!"

Ken took the old gentleman's meaning perfectly. For one thing, it *was* a beautiful morning—the first really joyous spring day the year had given; for another, he feared there was going to be some unpleasantness with his form-master owing to differences of opinion about the meaning of the Pragmatic Sanction and the causes of the War of the Austrian Succession. And for a third thing, Ken felt he ought to be out-of-doors, seeking adventures. The Old Chap had hit the right nail on the head; he was *not* keen on lessons to-day. And as he looked out upon the sunny fields and gardens he was aware of a distaste for school, such as he very seldom felt.

A bus whizzed past, bound for a big seaport, twenty miles away.

"I'd a jolly sight rather be in that bus than in this," said Ken. "I say, you know, there may be chaps in that bus going off on adventures! Starting off for Africa or South America! Don't you wish our driver would suddenly turn round and take us off to the docks, before he could be stopped. Suppose he said: 'Come on, you stuffy old blokes, you've jolly well got to have some adventures. We'll just have time to catch a ship that's starting on a voyage of discovery, and I'm going to put you all on board!' Wouldn't it be fine if he *could* do that?"

"What should we seek to discover?" asked the Old Chap. He was unusually grave, and his voice serious; almost as though he thought there was a possibility that the bus might actually turn round at Ken's behest and set the passengers on some wild and strange hunt for wonders.



SCIENCE AND THE FARM

A picture of the chemical works at Billingham which have grown up round the old Billingham Grange farmhouse seen in the picture. At the side is shown a type of the early nineteenth century farm-worker who has been replaced here by the chemist and mechanic. But other farms benefit from these works, for they make nitrates which form the basis of most artificial manures.

"What would you like to discover, young man? An island in an uncharted sea, or a new bird or beast or microbe?"

"Well," said Ken, "I'd go for the island, of course, because I might find all sorts of new and unknown things there, mightn't I? Besides, even if I didn't make any real discoveries, I'd be bound to have real adventures, looking for things to discover."

"You think the adventure of discovery is more important than the fruits of discovery, eh?"

"I don't know," Ken admitted. He had not expected to be plunged as deep as this. He had not expected the Funny Old Chap to take him quite so seriously. "I don't know. Only it must be splendid to go exploring. Explorers are bound to have adventures, you see, and after all, it does seem a bit hard that chaps like us, who have to go into dull old offices and shops when we leave school, can't do any exploring or have any real adventures."

"You can be an explorer, if you want to be one. You can have adventures every day of your life. You *do* have them, every time you use imagination."

Ken was not listening. His eyes were fixed on the big hoarding at the corner of First Avenue, one of the new, wide thoroughfares built on the outskirts of the town. A sudden prosperity had come to the old market town where Ken went to school, and new industries filled new factories arisen where fields and market gardens had been but a few years before. The traffic went by the new by-pass, built to avoid the old, narrow, winding streets, and from the by-pass three fine streets—First, Second and Third Avenues—branched off. Everyone was very proud of these new streets, although they had little to show except half-finished shops, looking lonely and forlorn; estate agents' boards and

builders' litter; for everyone felt how splendid they might be, if ever they became flanked by noble buildings—some day.

"I say—here's a bit of luck—'The Cipher of the Ring' at the Regal! This week!" Ken nearly twisted his head off in his effort to make the most of the poster. "I shall jolly well take Mother to that!"

"Indeed? Is your mother interested in dactylography?" inquired the old gentleman politely.

"Good gracious, no! At least, I don't know what that is! But this is a talkie, *I* mean. It's a wonderful detective yarn, about an awful kind of jewel, in a ring that was found buried in Egypt or somewhere. Well, this jewel is worth hundreds and thousands of pounds—at least it would be, only it sends out some kind of mysterious rays that make people go blind when they look at it."

"That would certainly seem to depreciate its value," agreed the Old Chap.

"Yes—but wait. There are some tiny diamonds round the jewel, arranged in a very queer sort of pattern, and there's a crook in this film who thinks the pattern must be a cipher telling how to make the ring safe, you see."

"I fear not as lucidly as I could wish. But proceed."

"Well, the hero of the film is quite a young chap (he's not much older than I am, I should think), with a beautiful voice. This chap is engaged to sing by the man who owns the ring, because when the ring was given to him by the high priest of a temple somewhere——"

"I suppose the jewel was an incubus and the high priest was glad to get rid of it."

"I don't know what sort of a jewel it was. But anyhow, there was a legend that if you sang to the jewel on just the right notes, it could cure some disease, and the man who

has the ring has a daughter, you see, and she has this disease, and so——"

That was as far as Ken got with the story of the Cipher of the Ring. A pity, for it promised to be interesting. It came to a sudden stop with the interruption of a bulbous, fussy little man who sat on the other side of the gangway.

"I never heard such childish nonsense in my life!" he exploded. "I can't sit here and listen to such drivel."

Ken would have liked to point out that the bus having stopped, the explosive gentleman could easily have got off, but fortunately his politeness saved him.

"These horrible picture-houses put the most preposterous ideas into people's heads, and they ought to be more strictly controlled! Nonsense, sir—contemptible nonsense! This boy," he continued, still spluttering angrily, "in common, I don't doubt, with a thousand other ignorant and misguided fools, is eager—actually eager—to waste his time absorbing the absurdities of a trumpery travesty of truth! A trumpery travesty of truth!" The fussy little man said that twice because he thought it sounded well. "Such distortions of scientific fact as emerge from this boy's jargon are only fit entertainment for magic-ridden savages."

"Magic-ridden savages! Of course! That expresses it exactly. Come, Ken—we'll get off here and see what the savage thinks of us and our magic. It's all here, just round the corner—the savage and the magic, exploration, and adventure, and a detective story that has a new thrill with each step we take. Come along, my boy—off you get!"

The bus had stopped at Third Avenue. It was not Ken's proper place for getting off, but his friend was so insistent that he did not like to protest. Indeed, the Funny Old Chap pushed and pulled and shoved him so that there was really no alternative. They stood together at the corner.

"A stupid man to spoil your story of the wonderful ring. But no matter, I'll go to the Regal and learn the secret." The Old Chap chuckled. He touched Ken's elbow and pointed. "You asked for adventure. See, even the city fathers point the way in the names they give the streets. What does it say there, on the name board?"

Ken was puzzled, and slightly disturbed by the thought that the Old Chap was a little mad, so thrilled and excited he seemed.

"Third Avenue," said Ken.

"Rubbish, boy! Stuff and nonsense! You can't spell. Shuffle the letters about a bit and try again. *Third Avenue* is only an anagram. Don't you see? For right-thinking people like us those letters spell——"

"Yes, of course they do—by Jove, how splendid!" Ken gave a whoop—a sort of triumphant yell that rolled and echoed down the busy street till it seemed that all the people there, office boys and office girls, shopmen and shopwomen, people walking, riding, hurrying, sauntering—each atom of the human wave there flowing, shouted in harmony with him:

"It means—it means—*Adventure-Hi!*"

"Adventure-Hi! Our street of adventure, Ken," said the Funny Old Chap. "It points the way to all the things you find so thrilling. All the dangers and excitements of exploration and discovery are to be read in these shop windows. The spells of the magicians are cast upon the forces of Nature, taming them and compelling them in a thousand ways to aid our happiness and comfort. That savage there" —the Old Chap jerked his head, and Ken knew that he meant the negro boy above the tobacconist's, an effigy whose wooden features had grinned upon the street for a hundred years or more—"that savage there must think he's magic-

ridden with a vengeance! He must think it odd how little respect we seem to pay to our magicians, strange to see how calmly we look upon their spells and wonders."

"Why, yes," said Ken thoughtfully, "because we're so used to them. When I first went to the talkies they gave me a sort of choky feeling—not the story (that was frightfully feeble), but the mysteriousness of sounds coming out of a cinema film. Well, it was like magic, wasn't it?"

"Yes, and I expect you will soon be looking-in and listening-in to actual events taking place hundreds of miles away. And I hope it won't be any less like magic when you have found out that our magicians, our inventors, chemists, engineers, electricians, are quite willing to share their secrets with you. There's some wonderful detective work going on, and no charge is made for leave to pick up the clues. Why, boy, explorers are setting out in every direction, at this very moment, and they all invite you to take part in their expeditions! Third Avenue looks to me very like the deck of that ship starting off on a voyage of discovery that you were so eager to join! Only the voyage is to be longer and fuller and the treasure-seekers will return with riches such as you never dreamed of! A most exciting voyage, Ken! You can join the ship, if you have a mind to, and care to work your passage."

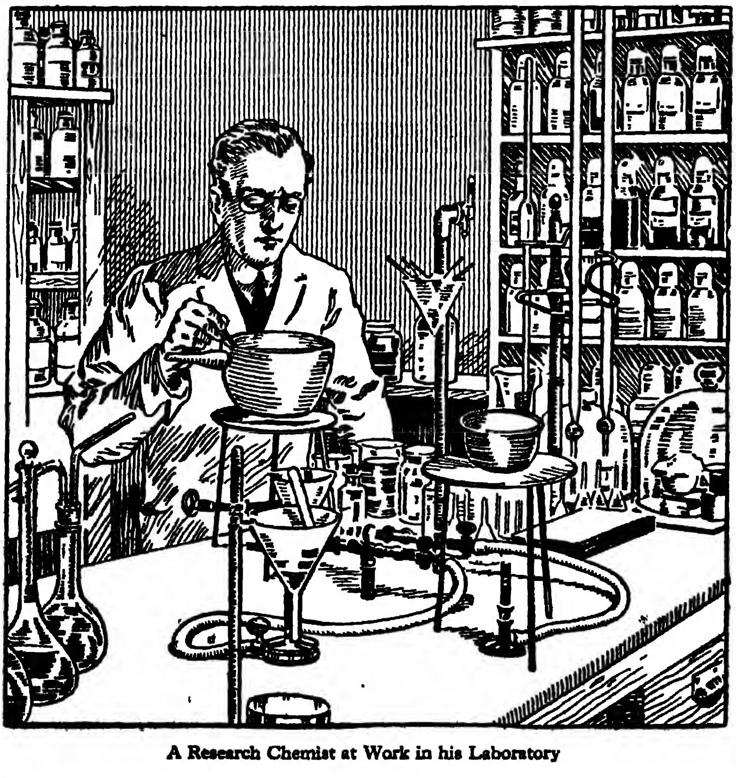
For a moment Ken had the oddest illusion. The Funny Old Chap seemed to be transformed. He was a ship's officer—of a sort, in a uniform—of a sort. He seemed to Ken to be terribly encumbered with strange and complicated instruments. And then there came a mist, and Third Avenue had gone; and he was at the docks beside a huge ship of strange and unfamiliar lines. No, it wasn't really like a ship—there was far too much machinery on the decks, far too many instruments. Still, he could hear

the surge of the sea, surely? The sound of machinery, was it, coming from far off? Or the roar of some fierce and terrible furnace, as when they make steel?

He knew it was only the traffic and a man with a blow-lamp in the man-hole in the pavement.

" What ship do you mean?" he said.

" The good ship *Science*, Captain Daring—outward bound for the Universe Around Us. Will you join her?"



A Research Chemist at Work in his Laboratory

CHAPTER II

Street Conjurers

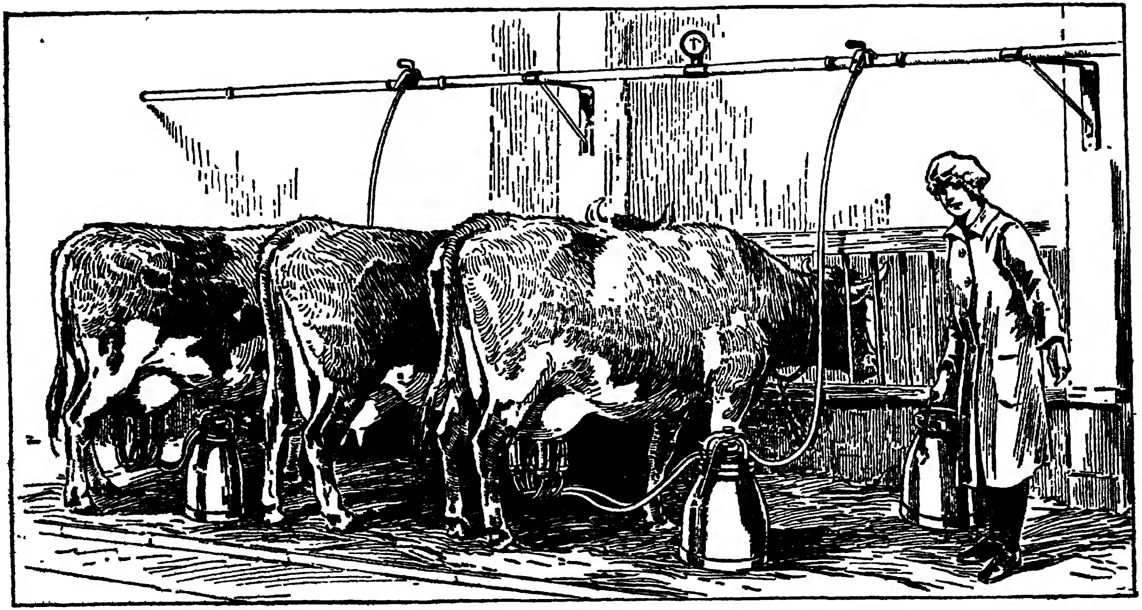
Ken soon found that the voyage of exploration on which his old friend had started him fulfilled the promise made for it. The Old Chap had only jogged his imagination a bit, and Ken there and then began to look beneath the surface of the things around him, and at once he had a passport to the world of wonders where roams the good ship *Science*. Well, we're all on the threshold of that wonderland. The way in is really very easy, as the Old Chap showed. Some of us go in a little way, perhaps through doors marked *Wireless*, or *Motors*, or *Photography*, or *Flying*, or other labels of the kind, and then we become frightened and turn back. That is a pity, because we are often scared by bogies that are nothing worse than hard names, after all.

The High Street is quite a good place to start. If you have not a Third Avenue, any other street will do as well, as a way in to the wonderland. We might start at the picture-house, with its magic of movement and of speech conjured out of a beam of light and a ribbon of celluloid film. A long, long way from our picture-house there was a chemist-magician who cast a spell upon some cotton and some nitric acid. Hey-Presto! It became celluloid, for camera films. Hey-Presto again! It is gun-cotton, to blow the place to bits. Another wave of the magician's wand—and behold, the celluloid is rayon, soft and silky, in glistening piles at the draper's, or in dresses of lovely colours. Another wave, and the celluloid-gun-cotton-rayon material is once again transformed into something quite different in appearance and use. It has become a lacquer-like paint, in

brilliant colours that tempt us to begin home decorating.

That is not a bad conjuring trick, but there are many to match it in our street. Every shop is stuffed from floor to ceiling with veritable surprise packets. I can't think of anything that is offered in any of them that has not the right to bear the label " A Present from Science ".

Here is the Provision Merchant's—surely there are no " presents from science " in his eggs and butter and cheese and bacon! Let's ask him. . . . " Eggs, sir? Well, I don't know how the poultry farmers would get on without a bit of science, indeed I don't. Talk about counting chickens before they're hatched—why, the chicks come out of the incubators just as regularly as china eggs come out of a machine! Then (because they are hatched in the dull days of winter) they give them artificial sunlight, ultra-violet rays to make them grow. And when they're grown, and ready to lay, the fowls are just egg-laying machines themselves. Science has given them exactly the right kinds of foods to turn into eggs without any waste. I don't know if scientists will ever make a hen's egg without a hen, but if they do *I* shan't be surprised. . . . Butter did you say, sir? My word, you're right! Science has made the dairy industry, and no mistake. Milking cows by electricity, to begin with, and all the other processes done by machinery—you wouldn't believe what ingenious things they've thought of to save time and money, as well as to make everything as safe and as wholesome as can be. Now, take vitamins, the chemical substances that exist in animal and vegetable foods and do so much to keep us in health. Isn't it wonderful that chemists have found out how to make most sorts of vitamins, so that they can be added to foods that are wanting in them? I like to think of vitamins as concentrated sunshine, for it is sunlight that makes them. Look at this New Zealand



MILKING COWS BY ELECTRICITY. The vacuum or continuous suction for the milking is created by an Alfa-Laval Pulso Pump (not shown), which is fitted with an electric generator. This creates a low-tension current. A contact breaker makes and breaks the current. The electric impulses are transmitted through a cable along the pipe-line over the cow's heads. This pipe-line has special stall-cocks which connect up with the pail of the milking units. The electric impulses alternately attract and release a magnetic pulse valve so that a rubber lining of the teat cups alternately contracts and expands (acting like the tongue of a calf) under the influence of suction (from the pump) and atmospheric pressure.

butter, please, lovely butter, chock-full of concentrated sunshine, in perfect condition after a journey of 17,000 miles! There's science been at work for you, to make that possible. And this margarine, now, just let your mind run backwards with that little packet. Coconuts from the South Seas, ground-nuts from West Africa, going into huge factories full of wonderful machinery and coming out as a good wholesome food that's a boon to millions of poor people. Yes sir, there's plenty of science to be found in a provision shop."

Here is the greengrocer's. Perhaps we cannot expect this shop to be very scientific. Lettuces and cabbages and onions just grow. Hullo! Our greengrocer looks indignant and holds out a detaining hand.

"Lettuces and cabbages just grow, do they? Don't you believe it! They have to be grown—and very scientifically, too. The grower has to "feed" his plants with the sorts of foods best suited to their needs, and if it hadn't been for the help of science we should all be in a fair way to starve by this time. Not only would there not be enough vegetables, but there would not be enough corn to make our bread, so it's a blessing for all of us that scientists can provide the right foods for different kinds of plants. There is the nitrogen, for instance, that plants require. A great deal of it comes from the gas-works in the form of *sulphate of ammonia*, and some is actually made out of the air by a wonderful chemical process. Fancy getting a chemical, rather like dirty salt, out of the air! Then again science has found ways of fighting the diseases and insect pests that prey on our food plants. Please look at all this lovely fruit before you go. It's gathered from every quarter of the earth—there's science there, and romance enough to fire the dullest imagination. These grapes, now, with the

bloom still on them, and these luscious delicate peaches, were grown in South Africa."

Let us pass on. We will skip the motor garage, for we know that that is an establishment that invites longer excursions in science than we can spare time for now. Science is writ large all over it, from the petrol-pumps in the front to the piles of old tyres at the back. We may peep in at the windows of Mr. Aktis,[1] the optician, as we go down the street. He will have to talk to us in another chapter, for he is truly a magician. Why! his stock is mostly bits of glass! With some of the bits he gives good sight to people with poor eyes; with others he makes binoculars and telescopes; with others microscopes to bring the invisible to our sight. There's a spectroscope on the shelf there, to show us how the rainbow is made. Now look in the periscope in the corner there, and you can see the workmen grinding lenses, though they are right out of sight on the floor above. Yes, we must talk to old Aktis, later on, for he certainly is a magician, with his lenses, prisms, mirrors—just bits of glass. Though he drives an old trade he is quite up-to-date, you see, for his name is stuck on his shop in the latest fashion. It is written in a continuous glass tube, and at night it glows with fire. The tube is a *neon* lamp. It is filled with a gas extracted from the air—we are breathing tiny quantities of it at this moment—and it gives out a bright light when electricity is passed through it.

Lots of other people in the High Street are doing things with the air, besides breathing it. The magicians have taken it to pieces and handed the pieces over to those who want them in their daily work. Air is a mixture consisting of four parts of the gas nitrogen and one part of the gas oxygen, together with very small proportions of other gases,

[1] It would be odd if that were his real name, for it is the Greek word for *ray*.

like the neon that makes the wonderful ribbon of light that spells old Mr. Aktis's name. The greengrocer told us that his friends the market-gardeners use nitrogen to make their plants grow.[1] Mr. Tugg the dentist uses nitrogen too, or rather, a compound of nitrogen and oxygen, the nitrous-oxide gas he gives his patients to make them insensible while he pulls their teeth out. He keeps it in a strong steel bottle, where it exists as a liquid until the patient needs a dose of gas.

And we can see another use for a part of the air in the open trench at the corner of the street. The workmen there are using oxygen to obtain the intense heat required to weld up the ends of the steel gas-mains they were obliged to cut. The steel must be made quite soft, so that the two pipe-ends become joined as one, and they are using an oxy-acetylene blow-pipe. The oxygen was obtained from the air, or else from water, which is made of hydrogen and oxygen, and the workmen brought it with them in a big steel cylinder, where it is held in under tremendous pressure.

We must watch the traffic as we cross the street. Listen to the hiss of the tyres! Do you know that the cars and lorries are running mostly on air? I do not mean under their wheels, but in their engines. The gas burning in the engines is about 98 parts of air in every 100 parts of gas. The air and that tiny proportion of petrol gas are tightly compressed before being ignited; and here is plain compressed air helping to build the new telephone exchange. You can hear the clatter of the pneumatic riveters, tools using air under great pressure to give a punch that

[1] It may be wondered why plants do not take the nitrogen direct from the plentiful supply in the air. It would be much easier for us all if they could do this. Yet plants are really better off than animals, for the former can absorb *some* of their food from the air—the carbon, which exists in the atmosphere as carbonic acid gas. The nitrogen has to form compounds with substances *in the soil* before the plants can use it.

squashes flat the ends of the thick rivets in the steel girders.

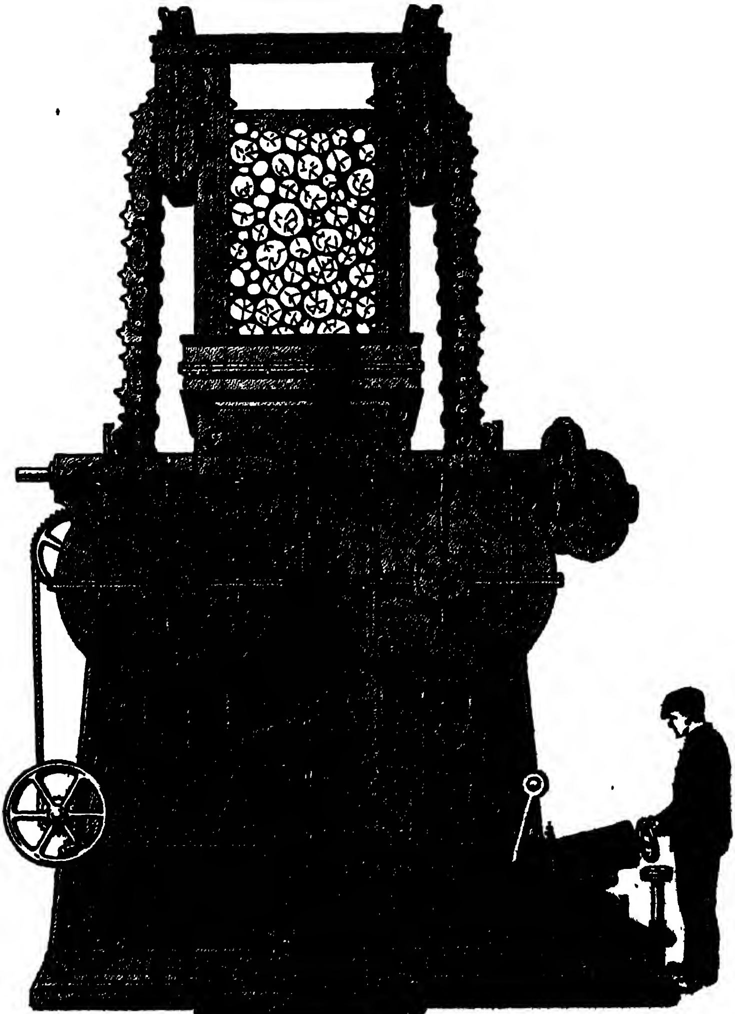
But look here—this is interesting—the butcher's boy is pumping up his bicycle tyre! He's putting some " beef " into it, too. That is because he has just been helping to unload the lorry that brought the beef from the cold-storage warehouse. It was covered with hoar frost and his hands are cold. Now he is warming them beautifully. He thinks the warmth comes from the *friction* of his bicycle pump, because he doesn't know anything about the properties of gases. He does not know that he cannot compress a gas—or a mixture of gases, like air—into a smaller space than it can comfortably occupy at a given temperature without making it hotter. If he knew this, the errand boy would perhaps realize that he is warming his hands by a method exactly the reverse of the one they used at the cold-storage warehouse. To keep the beef frozen, the cold-store people first compress a gas, and then let it expand; in doing which it takes enough heat out of water to turn it into ice. That is the magic that gives you an ice on a hot summer day, and we will get the magician to show us just how the trick is done, later on.

Perhaps you have noticed that in the High Street there are a good many agents of one kind and another; insurance agents and estate agents, travel agents, employment agents, wholesale agents. There is even one whose announcement makes us shudder slightly—a scholastic agent. Pass him quickly. We won't bother about any of them, dull fellows one and all, though they may improve on acquaintance. But here, standing at the curb, is the humblest agent in the town, too humble to own a shop or even an office with a brass plate, like the other agents. But if he had a brass plate, or a shop sign, this is what he might put on it:

A. WONDER: NEWSAGENT
High Class Magic in any Quantity
Exploration and adventure guaranteed

And nobody could say he must not, because we all know (or ought to know) that the shabbiest newspaper seller who stands at the dingiest street corner is really and truly an agent of magicians of the highest order. Just think: the very substance of his wares—the paper—is the outcome of mighty magic. A few months ago it was a tree growing in a Canadian forest. The tree was cut down and ground to pieces, and boiled to pulp and changed into paper—a broad white band, five miles long. The huge roll of paper was then swung into the roaring printing press, and began a terrific journey between revolving cylinders. It was stretched and twisted, bent back upon itself, and turned into folded newspapers at the rate of about 40,000 an hour. It is only cheap paper; it is only three one-thousandth parts of an inch thick; but the giant printing presses—more than a hundred tons of complicated metal in rapid motion—deal so gently with the fragile paper that they never tear or injure it, though hour after hour they clatter and roar and mile on mile of the thin paper becomes a record of the world's work and play.

Think, too, of the magic that lies behind this record; the magic in the inventions of rapid communication that bring us news of events even while they are taking place. Voices seem to speak to us across the seas when we open our newspaper, and a thousand wonderful devices vibrate to tell us what the world is doing. And what of the events caught by the picture page? Surely magic is there! A few hours ago light flashed through a camera lens and now the action of that instant is fixed in printing ink, a record that millions



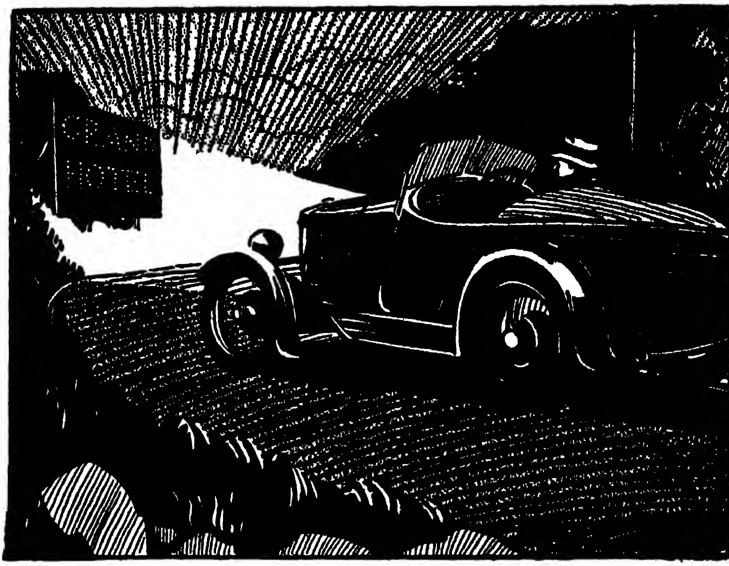
GRINDING DOWN TREES FOR PAPER PULP

The machine shown is known as a Voith Continuous Grinder. The logs are moved downwards by a continuous chain, each link of which carries a wedge-shaped shoe. These shoes grip the logs and hold them as shown above, pressing them against the grinding stone until they are ground to powder. The man is working a gear by which the stone can be " dressed " while the machine is working.

may view. Yesterday, in New York, the President of the United States made a very important speech. Even while he spoke, millions of listeners in Europe and America hung upon his words. To-day, all who will may read his speech. And more, they may even look upon the President and mark in face and attitude the earnest purpose of his message. For the camera caught and held them, and they were flashed across the Atlantic—a photograph carried by a submarine cable! They might have sent the picture by wireless? Of course they might. A little magic more or less is of small account to our newspaper seller, there is so much of it behind him.

You would like to stop at the wireless shop? And so would I. But once we were inside, Mr. Sparks would start us on such a long voyage of exploration that we should almost certainly outstay our welcome. So we will make a note to visit him another time. But while we are just glancing at Mr. Sparks's window, I will tell you about the wonderful sign he has helped to put up on the main road outside the town. It *looks* just like an ordinary illuminated sign. It stands back a little from the road, and it says GRAND HOTEL in coloured electric lamps. Now, if you stood by the sign at night you would notice that it is not illuminated all the time. It flashes into life, stays alive for a little while, and then goes out. Presently the lights come on again. It will soon occur to you, if you watch carefully, that the intervals for which the sign remains on or off are very irregular. Sometimes it flashes on and goes out again quite quickly; at other times it stays on a long time, or stays off a long time. It seems quite without method in its timing.

Presently, however, you might notice that it is *always* shining brightly whenever a car approaches the town. Every oncoming car is accosted by the fiery words GRAND



An Automatic Sign controlled by the Headlights of a Motor-car

HOTEL. Perhaps there is an observer hidden somewhere to switch on the sign, so that it shall command the notice of every motorist. Yes, there is such an observer, an observer with a wonderfully keen eye for approaching motorists, an unfailing eye. It is not a human eye, however. The sign is controlled by a marvellous device known as the electric eye, because it is electrically sensitive to light. The sign is switched on by the rays of the motor-car headlights as they swing past a point on the road nearly a quarter of a mile from the sign. A motorist coming down the road at three o'clock in the morning would see the brilliant sign ahead of him, and he might well think how wasteful it was to leave it burning all night, not knowing that it would switch off automatically almost as soon as he had passed it, or that his own car had been the means by which it had become lit

up. "Electric Eyes" of this kind (they are also called light-sensitive cells) control all sorts of apparatus more accurately and delicately than is possible by human intervention. They are used for rapid counting. *You* cannot count a hundred in a second, but the electric eye can, and does, unerringly. It can detect an outbreak of fire, give the fire alarm, and begin to put the fire out—all in one wink, so to speak. And though it is the Fireman's Friend, it is also the Burglar's Terror, for when it is given the job of guarding valuables it starts a terrific racket of bells and gongs as soon as anyone approaches. Except that it can't bite (though it could quite easily shoot a pistol at us), no watch-dog can compete with it.

So we come to the end of our street. There is only the sweet shop left. A pity to pass it, you think? Perhaps it is! If the butcher, the baker, the fishmonger, the greengrocer, the provision merchant, and all the rest—if they all offer us passports to this wonderful realm of science, it would be odd if we could not find a way in through the seductive doors of the sweet shop. Those boiled sweets look rather attractive, don't they? The twopenny packets, done up in that thin, transparent, clean-looking cellophane. Well, that is wood, though it doesn't look like it. And the sweets—raspberry, pear, and pine-apple drops—cheap, wholesome sweets, those—and they last well! But don't run away with the idea that they are made from raspberries, pears, and pine-apples. The flavours come out of the gas-works. There's magic in them.

CHAPTER III

The Universe Around Us

There was a good deal of magic in the last chapter. I wanted to impress on you the wonder of achievement, and to help you to feel the romance that dwells in our knowledge of physical things. Some people think that romance belongs only to ages that are past, or to lands that are far away; but it truly surrounds our own lives and the ways that we tread to-day, in far fuller measure than ever before.

Perhaps you have said to yourself: "It's not magic, really. Magic is some result brought about by influences beyond the power of man. It disregards the 'laws of nature'. In fact, there is no such thing as magic. People have only imagined it to exist. Those wonders in our street are a great deal more wonderful than any magic; because anyone of us could bring them to pass—if he knew how." Exactly. You could make a motor-car, a microscope, a neon lamp, or an electric eye, better perhaps than any now existing—when Science has shown you the way. That is what we are always trying to do, if we happen to be inventors. We try to make things better, cheaper, more efficient; or to bring new forces to the service of humanity. And for any improvement in the material things surrounding us—our food, clothes, tools, toys, everything—we look to science to show the way.

And what *is* science? We know that it is something that confronts us at every turn. We are told that we live in a "Scientific Age". So we do—but people forget that the age dawned almost as soon as man started to think—as soon, indeed, as he began to respond to one of the strongest

of his instincts, the instinct of curiosity. Science is *ordered knowledge*; knowledge arranged in such a way that we can make use of it. Knowledge by itself is not science, though the word comes from the Latin verb *to know*. Suppose you learnt all the words in your French vocabulary, they would be utterly useless to you unless you learnt as well their meaning and how they must be arranged to make a language. Or suppose you had all the pieces of a complicated machine; wheels, levers, cranks, gears, nuts, and bolts; until you discovered what each piece was for, and how it could act in harmony with all the other pieces—not until then could the pieces become a machine. It is somewhat the same with science, for we can liken the *facts* of science to the parts of our machine. Some of the facts are very interesting in themselves, just as the gears and levers may awaken our interest, though we are ignorant of their purpose.

Science arranges the facts that wise men have discovered, century by century, as they probed the nature of the world. Sometimes the discoveries were accidental; more often they happened because men were curious about the things around them. They could not look at a rainbow, or listen to an echo, or watch the river flowing to the sea, or steam coming from a kettle, or ice crystals slowly gathering on the surface of a pond without puzzling their wits about *why* things behaved in such queer ways. And so, little by little, science has come into possession of a vast and richly-filled treasure-house wherein the riches are facts.[1]

In this treasure house of ordered knowledge the riches

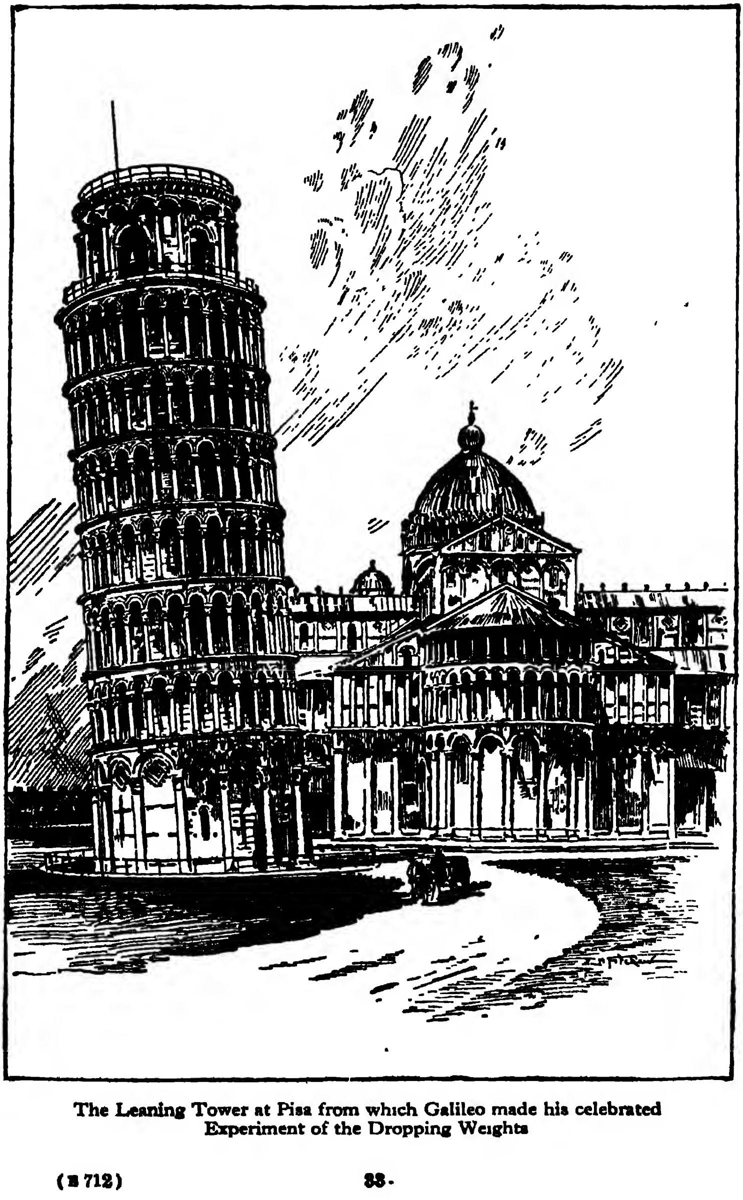
[1] The facts of science are the demonstrable properties of substances—the properties that always make them behave in similar ways under similar influences. Thus, water *always* changes to steam at a given temperature and pressure; a pendulum of a given length at a given distance from the centre of the earth *always* beats in the same time; a falling body increases in speed at a constant rate, and so forth. Such facts are called the "Uniformities of Nature", because they show us that the properties of matter are governed by "laws" that are always the same for the same conditions. These laws of physics, i.e. physical science, explain the relationships of the facts in mathematical terms, so that anyone can prove them for himself. "Physics" and "physical" simply mean *natural*, from the Greek word for nature.

are arranged like the goods in a warehouse; every treasure-fact has its proper place and proper name, and the system is so exact that they cannot get muddled up. And you and I may enter the treasure house when we will; we may help ourselves to these facts about the properties of matter, and use them as the cogs and levers of machines, and set them to work for the benefit of mankind.

One of the very first questions inquisitive persons ask of the things around them is, what are they made of? We cut down a tree and we say " That is wood ". We look at the axe that felled the tree—that is steel, we say. But what are wood and steel? The axe and the tree are very different, by whatever standards we compare them. They not only look different, all our senses tell us that they are different —touch, taste, smell, and even hearing. Even with his eyes shut no one would confuse the axehead and a piece of newly cut wood. Suppose we carry the comparison a little farther; we discover that one is much harder than the other; one sinks if we put it into water but the other floats; we can easily burn the one but we cannot, by any ordinary means, burn the other.

Yet these very different substances, wood and steel, have some likenesses, or " affinities ". We call them both solids —they have shapes; they fall to the ground if they are dropped. And if we took them to the roof and let them both fall off at the same instant, we should find that there was no difference in the time of their journeys to the ground; they would reach it together.

This very important likeness or " uniformity ", *that all bodies whatever their weight fall through a given distance in the same time* (except those that offer a great deal of resistance to the air in proportion to their weight, such as feathers), was discovered nearly 350 years ago by a very remarkable



The Leaning Tower at Pisa from which Galileo made his celebrated Experiment of the Dropping Weights

Italian scientist named Galileo. Galileo made this discovery by dropping two weights, one of 1 pound and one of 10 pounds, from the top of the famous leaning tower of Pisa, but for a long time people refused to believe that it was really true. In those days it was thought that heavy bodies must fall at a faster rate than light ones, and they were still more surprised when it was learnt that the same law applied as well to bodies flung *upwards* into the air; there is no difference in the time of the ascent of bodies whatever their weight, if they start off *with the same speed.* We shall come upon Galileo and this law of his again.

We might have added to the list of differences between the steel axe and the wood we cut with it the one that probably occurred to us first of all. The tree from which the wood came is a plant; and a plant is something with the most remarkable property in the world. It is a living thing. It has the power to *feed* and *grow* and *reproduce* its kind. Animals, too, have this wonderful power. But the steel axehead is a non-living thing. It is made from iron that was dug out of the earth. If we want more wood we can sow seeds of trees, and in time we shall have new forests, but if we ever dig out all the iron ores,[1] why then, there will be no more iron ore, for iron is something that cannot grow. Science distinguishes the substances that we get from living things by calling them *organic*, for they come from things having organs for growth and reproduction. That leaves a great class of substances that exist independently of life, like air and water and rocks. These are called *inorganic*. Sticks are organic substances, stones are inorganic. Soap is an organic substance, for it is made of vegetable or animal fats, though they were boiled with chemicals that are inorganic. Glycerine is likewise organic,

[1] Iron is so plentiful that there is no fear that we shall ever use it all up.

for it, too, came from the fats when the soap was being made. What about the bottle that holds the glycerine? We should say at once that glass is an inorganic substance, for it is made entirely of minerals, that is, things that are dug out of the earth, or *mined*. If you had a tin of toffee you might say that the toffee was organic, for it is made of sugar and sugar is a plant product; but the tin containing the toffee is made of metal, and metals are minerals, and minerals are inorganic. This very important difference between living and non-living substances and their products ought to be easy enough to understand, yet people are often confused about the meaning of these two simple words, organic and inorganic.

We have yet to satisfy our curiosity about the wood and the axe. So far, we know next to nothing about them. What we have learnt mainly concerns their nature—hardness, weight, shape; and we know just a little about their behaviour; as, that they are attracted to the earth, and that it requires an expenditure of energy to overcome this attraction. We know that everything is attracted in this way; that the law of gravity makes things fall to the ground. To move a thing, no matter whether it be light or heavy, we must use some kind of force or power. The power to do work—any kind of work—has another name; it is called *energy*. Our everyday experiences teach us a good deal about energy, which is quite the most important property of matter. Life itself depends on a constant exchange of this mysterious power to do work—a bandying of energy to and fro between one thing and another. Each breath we draw, each heartbeat, each thought or action is the result of an exchange of energy. The exchange goes on all the time, everywhere, in everything. We all know that it drives ships and trains and all sorts of machinery; we know that it needs a lot of

energy to jump six feet or to run a mile. And we find it in the rocks and in the winds and the waters; in short, wherever matter is, we find energy stored up or passing on from one thing to another. So we ought to know something about it, since we cannot move an inch without its help.

Now, although matter has this power to do work, it has also another property. A very annoying property we often find it, especially in the lawn mower and the garden roller. Once we have got them moving it is not difficult to keep them moving; but why does it take so much more pushing to start the mower, and such a long, strong pull to persuade the roller to roll? The trouble with them is that they possess something called *inertia*. Inertia is the Latin for "inactivity", and it denotes a property of matter that is unvarying throughout the universe, just as gravity is unvarying. This universal property keeps a resting body at rest, or a moving body moving in a straight line at a uniform speed, until some force alters these states.[1]

Now, all the properties—the differences and uniformities we have just glanced at—are properties belonging to all things throughout the universe. The weights of our lumps of wood and steel,[2] the properties of inertia and motion, the ways in which they respond to light and heat, sound and electricity—all these things are found out through the great department of science called *Physics*. Physics tell us about the structure and properties of matter; and we cannot expect to know the marvellous beauty and unity of the

[1] Galileo showed that a body at rest could never begin to move by itself, and that a body in motion could never come to rest by itself. It was the great Sir Isaac Newton who first explained the simple laws which govern inertia and motion. They are the foundation of the science of *dynamics* (Greek, power), which deals with the behaviour of matter in motion. Engineers would never have been able to perfect the beautiful machines that surround us unless they had understood dynamics. In locomotives, motor-cars, electric dynamos—in every kind of engine, in fact—this science explains both the power required to move the machinery and also the strength required in the moving parts.

[2] We ought to know exactly what is meant by weight. It is the *mass* of a thing expressed in units that have been agreed upon, like grains, grammes, ounces and pounds.

universe around us unless we are willing to ask questions about the laws of physics. Sometimes the physicists answer our questions in ways that are hard to understand; and so lazy people—the people who "Can't be bothered" to use their wits—are often afraid to enter the treasure-house of Nature. Such people are very stupid, for they shut themselves off from the enjoyment of a vast store of riches.

The words *universe*, *universal*, have come up several times in the last few pages, and we may pause a moment to make quite sure that we know what they mean. They come from the Latin word *universum*, which means "the whole". They are often used in a very restricted sense, so that universe becomes another word for "the world" and universal "everywhere in the world". There are "Universal Stores", "Universal Tourist Agencies"; and people speak of such and such a thing as being a universal custom or habit, meaning that it is common throughout the world. The true meaning of the words is far wider. When scientists talk of the universe they are thinking of the whole of creation—everything, everywhere. It is important to realize that the laws governing the properties and behaviour of matter are *everywhere* the same for the same conditions. They apply not on the earth only, but in the moon and the sun and the remotest of the stars—in short, wherever anything exists.

Now let us get back to our original question: what are things made of? We have just seen that the department of

We use these units for comparing the heaviness or *density* of substances. The mass of a body is simply the amount of matter it contains; its density is the amount of matter contained in a given size or *volume*, say, one cubic centimetre or one cubic foot. Thus the density of water at a *fixed* temperature (62° F) and at a *fixed* pressure (equal to 30 inches on the barometer) is one gramme per cubic centimetre. The law of gravity tells us that weights are proportional to masses; and it is very convenient to be able to compare the weights or "specific gravities" of different substances, and many highly ingenious instruments are used for finding them out. In every cubic centimetre of the elm axe handle there is only $\frac{6}{10}$ as much matter as in the same amount of water, but in the steel axehead seven and a half times as much. So we can say that water is nearly twice as heavy as elm wood, and steel nearly fifteen times as heavy. The actual densities of these three substances are: water 1, elm 0·6, steel 7 6.

science called Physics deals mainly with the states or *conditions* of matter; to obtain answers to questions about the *composition* of matter—what matter is made of—we must ask at another great department called *Chemistry*. Chemistry pulls things to pieces and explains how and why the pieces are joined together to form the hundreds of thousands of different substances that exist around us. It shows how the pieces composing one substance can be rearranged to form an entirely different substance. It shows, for example, that some of the pieces of matter that go to make the wooden handle of the axe we were talking about a few pages back are also used to make the steel head of the axe. I am sure I need not tell you that the arrangement of the particles of matter to form these hundreds of thousands of different substances is governed by laws that are always the same for the same conditions, just like the laws of physics.

A wise man of ancient Greece, named Democritus, who lived more than 2500 years ago, thought that all things were built up of tiny particles of matter. These ultimate particles were called *atoms*, because they were supposed to be indivisible. *Atom* is a Greek word of which the English meaning is "that which cannot be cut". Democritus supposed that there must be a different kind of atom for every different kind of substance; a water-atom, for instance; and an air-atom, an iron-atom, a wood-atom, a pudding atom, and a cake-atom, and so on—thousands and thousands of different atoms. Well, on this theory, we must be constantly adding to the list of atoms. Suppose we take currants and sugar and flour, spices, eggs, butter, milk, jam, and candied peel in order to concoct a really exciting cake. Would this mixture of the atoms of all the substances for which we have ransacked the larder result in a new and original atom of the substance called cake? Perhaps Demo-

critus wasn't fond of cake; because if he did eat it, he must have recognized old friends like the currants and candied peel; he could taste the sugar and, possibly, the eggs; in which case he must have said to himself: "Well, this looks like a lot of old atoms cooked up, and I don't believe its ultimate particles are really new!"

About the time of Democritus there was another Greek thinker who puzzled about the stuff that things are made of. His name was Empedocles and he lived in the island of Sicily. Democritus was not only learned and wise; he was good and just as well, and the people of his age loved and respected him. Empedocles also had a large following as a teacher, though he was really a bit of a quack. For one thing, he claimed to be a magician. The story goes that when he was growing old he threw himself into the crater of Mount Etna in order that people should think that he had been miraculously spirited away. But the volcano, so it is said, refused to be a party to this deception and threw the vain Empedocles' shoes back again.[1]

One of the things for which Empedocles' name has remained famous, even after more than 2500 years, was his theory that things were compounded of only four different kinds of atoms, and not of an infinite number, as supposed by Democritus. That was certainly a big reduction! Empedocles declared that everything was built up from four essential substances, which he called *elements*. They were earth, air, fire, and water. There was nothing else in creation.

I am sure I need not tell you that these four "elements" are not recognized as such by modern science. They are not elements, any of them. Nevertheless, men of science believed they were, until 300 years ago. They might not

[1] We don't believe this. The fable was probably invented by the philosopher's enemies, of whom there were many.

have taken Empedocles' word for it all that time, had not the great Aristotle said that it was true. Aristotle lived some time later than Empedocles and his greatness as a thinker so held the imagination of men, century after century, that no one dared to question what he had taught.[1]

It was an Irishman who showed that the idea was quite a false one. This was Robert Boyle, who lived in the reign of King Charles the Second. Robert Boyle is called the Father of Chemistry, because he showed that the theories of the composition of matter believed up to then were utterly false and unscientific. He was one of a very large family (he had fourteen brothers and sisters), and though he was a puny sickly child, he was sent to school at Eton when he was only eight. He was a very unpromising boy, with uncouth manners and a stammer he had picked up in imitating a friend, yet he grew up to be a very charming and polished gentleman with a very inquiring turn of mind. He made all sorts of experiments, and he formulated a law of gases that still bears his name.[2]

But, as I have said, the thing for which we have to thank Robert Boyle was his exposure of the ancients' notion of the four elements. An element, he said, was something that could not be split up into a substance other than itself.

In course of time, when other investigators had proved the composition of all sorts of different substances on the *analytical principle*[3] advised by Boyle, it was discovered that everything is built up by combinations of ninety-two different kinds of material. These ninety-two substances

[1] There is a very curious likeness about the "elements" conceived by the Greeks and those of ancient China. The Chinese also thought that everything was made of earth, air, fire, and water, but they added a fifth element, wood.

[2] Boyle's law shows that for a given quantity of a gas at a given temperature the pressure varies inversely as the volume. This means that if we *halve* the size of a vessel containing a gas we *double* the pressure it exerts on the surface of the vessel.

[3] Analysis is a Greek word meaning to "unloose". So when we analyse anything we loosen or separate all the parts of which it is composed.

are the elements of modern chemistry. We may think of the elements as the indestructible "bricks" of matter of which the universe is built. They can be arranged and rearranged in an infinite number of combinations, making all the substances we know, or shall ever know. But we cannot make new bricks, nor can we add to the number already existing.

Robert Boyle

It might well be supposed that the elements existed in equal quantities of each kind. Instead of that, however, there are very much more of some kinds than of others. Indeed, eight of the elements are so plentiful that between them they make up very nearly the whole weight of the earth; in fact, they leave only about a hundredth part of the weight of the earth's crust to all the others. The most plentiful of the elements is oxygen. "What! a gas?" you say. "Surely that must be very light?" Yes, oxygen is a gas; but it dislikes being left out of things and rushes to join with the other elements to make most of our liquids and solids as well. When oxygen combines with the element

hydrogen (in the proportion of one part of oxygen to two parts of hydrogen) the resulting substance is water. And, as you know, there is quite a lot of water in the world.

After oxygen, the most plentiful element is *silicon*, a non-metallic element that combines with oxygen to form silica, which is such a common mineral that it makes half the rocks of the earth. Granite (quartz), flints, sand, and sandstone are mostly silica. The next most plentiful are the metals *aluminium*, *iron*, *calcium*, *magnesium*, *sodium*, and *potassium*. Aluminium combined with silicon, oxygen and hydrogen makes clay. Calcium combined with oxygen makes lime.

Chemistry is a very fascinating science and I am sure you would be interested to know the means by which chemists have come by their knowledge of the way in which the elements combine to form chemical compounds; how they come to build up all the material things that make our world. In the next chapter I want to tell you something about atoms and molecules. The chemist's job, or part of it, is to knock the elements in things apart and to join them up again in different ways or proportions, so that they make something else. This sounds very much like magic; but it is the sort of magic that any of us can learn to perform, when we understand the laws that govern the linking together of the elements.

CHAPTER IV

Matter in the Making

It was the old Greek Democritus who said that we could not continue to divide up a piece of anything indefinitely without coming to a final or ultimate particle or grain of that particular material, which he called an atom; you remember, " that which cannot be cut ". I want you to think about this for a moment. Imagine yourself setting to work to find the atoms in a grain of salt. You would start by cutting off a tiny fragment, which you would then divide and divide again, until you could cut it no more. You come to a stop, but not because the tiniest speck of salt *cannot* be cut; only because your perceptions and your tools are too coarse to cut it. Suppose you handed over the fragment to some superhuman being with senses and instruments a thousand times as refined as yours; would he not be able to cut it into fragments a thousand times smaller than yours? We know that we cannot set any limit to the smallness of things, any more than to the bigness of things; and so it might well be that we could never hope to come in touch with the ultimate particle of anything. There may or may not be a limit beyond which a thing cannot be cut—but how can we ever hope to know?

Well, we do know. In another chapter I hope to be able to tell you *how* we know that there are really such things as atoms. Chemists can count them, weigh them, measure them. These ultimate particles of matter, the elementary bricks of which all things are made, are of a smallness so much beyond the power of the microscope to reveal that we can never hope to see them, however wonderful the microscope that might be invented. But there they are,

the separate, individual bricks, of some ninety different sorts—a different kind of brick for each element—with which God built the Universe.

I told you about the delicate, stammering, clumsy little boy, Robert Boyle, who changed chemistry from nonsense and guesswork into a very beautiful exact science. Seventy-five years after Robert Boyle had died there was born another boy who was destined to set this science on a still firmer foundation of knowledge. This was John Dalton. Robert Boyle was the son of an earl; this other boy, John Dalton, was the son of very humble parents who earned a poor living from a little farm, and by working at weaving when their outdoor work was done. They lived near Cockermouth in Cumberland, in the far north of England, and there John was born in 1766.

John Dalton

John Dalton was as alert and intelligent a boy as Robert Boyle had been a dull and clumsy one. John went to the village school, but left it when he was ten years old, having learnt all that it could teach. Presently he opened a school on his own account. I think he must have been the youngest schoolmaster on record, for he was then only twelve! So this boy grew up, part farmer, part schoolmaster, to become one of the most brilliant scientists, not of his age merely, but of all ages. So great was the honour in which his generation held him that when he died, in 1844, 40,000 people visited his coffin, where it lay in state, in the Town Hall at Manchester.

And what—you ask—did this great man do for science? He was the first to show that there is a beautiful regularity, or a symmetry, about the way in which the elements join together to form the wonderful variety of substances known to us. He showed that the smallest possible particle of an element—the atom of that element—has a definite size and a definite weight. This means that any one atom of an element is always exactly like all the other atoms of that element, and unlike the atoms of any other element. The discovery that each of the elements was composed of atoms that had quite definite weights was a very important one indeed. For to the chemist these distinctive *atomic weights* stand much in the same sort of relationship as a book-keeping system stands to a shopkeeper, or even his calculations to the mariner. They enable him to find his way about, and show him what proportions of the elements must be united—or pulled apart—whenever he wishes to change one substance into another.[1]

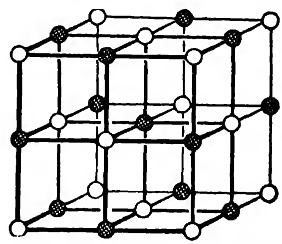
Perhaps our grain of salt will make this clearer. Suppose we start our investigation by chipping a little piece off the block of salt in the kitchen; if we looked at a fragment of this salt under a microscope we should see that it is composed of tiny crystals. Now, the most powerful microscope ever made would not show us more than this, and we might be misled into thinking that if we selected any single crystal we should really be looking at the smallest possible unit or complete particle of salt. "Here," we might say, "is the atom of salt." But we happen to know that there is no such thing as an atom of salt. The atoms belong only to elements, and salt is not one of the elements; it is a compound, built up by the union of two different elements,

[1] Dalton worked out the atomic weights of some twenty of the elements, based on the weight of the atom of hydrogen, but his calculations were not entirely accurate. The oxygen atom is now taken as the standard unit. Oxygen equals 16, and hydrogen 1·008, not 1, as supposed by Dalton.

sodium and chlorine. We know that this is so because we can easily prove it by experiment. Still, there must be a unit of salt, a smallest possible particle that cannot be divided without losing the properties and characteristics of salt. If we can find this unit, which is called the *molecule* of salt, then we may be able to see the two different kinds of atoms of which it is composed.

But we can never hope to see a molecule of anything. It is much too small ever to be visible. However, we may suppose that we have invented for ourselves a microscope capable of magnifying things at least 5000 times larger than any microscope now existing. With such a microscope we might be able to look upon the molecules in a crystal of salt, and it is certain that we should be fascinated by what we saw. We should notice, first of all, that the crystal was very loosely made. We think of it as continuous matter, but, if it could be magnified so that we saw its molecules, it would not appear continuous at all. It has something of the open nature of honeycomb, or sponge cake, full of holes—and more hole than substance! It is more like honeycomb, however, because the molecules are quite evenly arranged, so that they form a definite pattern, somewhat like a lattice-work, repeating itself over and over again throughout the crystal. And in whatever way we examine the crystal—frontways, sideways, or endways—we find the lattice work to be perfectly symmetrical, i.e. regular in every direction. And here I must tell you that by the use of X-rays scientists are able to say exactly what the lattice-work pattern is like in any crystal, or even tiny fragments of crystals. I think you will agree that this is a very wonderful feat, to be able to tell just how the molecules have arranged themselves, although it is quite impossible to see them! And you will be interested to know that this method of

crystal analysis has led to very important discoveries that affect our everyday lives. Such as: why some metals are much stronger than others, and what happens to them when they are put under great strains, as they often are in motor-cars and aeroplanes and, indeed, in most kinds of machinery.

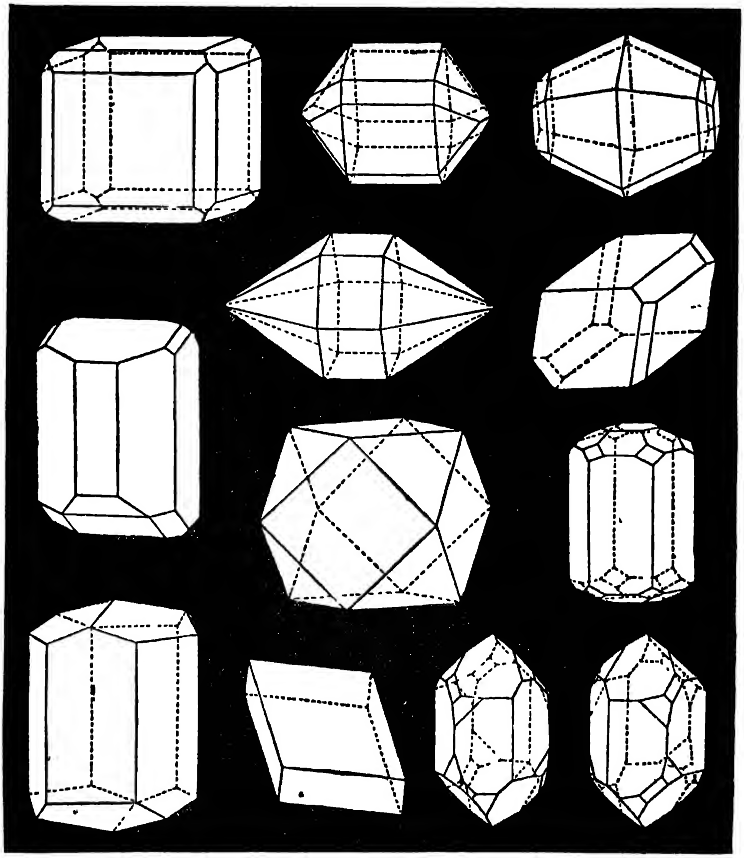


Crystal Lattice of Common Salt. The white balls represent sodium atoms, the shaded balls chlorine atoms

Nearly all solid substances are crystalline—their molecules are arranged in these nice, neat, regular patterns, instead of being all higgledy-piggledy. If they are all higgledy-piggledy, jumbled together anyhow, the substance is said to be *amorphous*. Glass and glue and barley-sugar are amorphous substances.[1]

But we must get back to the salt-crystal we started to examine under our imaginary super-microscope. We see that the molecules are touching each other only at certain points; if they were not, there would be no lattice pattern. What is more remarkable still, the molecules appear to be very impatient at being held together. They are in active movement, as if they were struggling against some force that kept each one chained to its neighbour in this extraordinary formation. We may think of them, without too much exaggeration, as couples taking part in a very elaborate physical drill display. The couples are close together, in ranks and rows almost touching each other, but not quite; and every couple, while keeping in the same position relatively to all the others, is in active movement. We can suppose each couple to be "marking time", swinging the

[1] An odd thing about glass is that glass-makers love to advertise their wares as "crystal glass," whereas glass is really the very type of a non-crystalline substance.



The beautiful symmetrical and geometrical forms of various crystals

arms, and moving the body this way and that, without actually moving from one spot.

We can go a little farther with our picture of the couples. We can imagine each couple to be composed of a boy and a girl holding hands. Joined thus, each drilling couple represents a molecule of salt. A couple is the smallest possible unit or complete particle of salt; if we do anything

to separate the boys and girls, anything to make them let go each other's hands, then the salt molecule breaks to pieces. It is not salt any longer, for we have brought about a chemical change. And the odd thing is that the individual boys and girls are in nature utterly unlike the salt molecules they formed when joined together. We find that they are the same only in a single respect, that of weight. The girls are atoms of the element chlorine. Now, when two atoms of this element join together, they make a molecule of a dense gas called chlorine, which is very poisonous to breathe. The boys are atoms of the element sodium, which is a metal. This metal sodium is a very strange one compared with most of the metals we are familiar with, such as iron, copper, tin, or zinc. It is so soft that it can be cut like cheese; and what is much more remarkable, it causes the water to fall to pieces so violently that it may catch fire. If we float a piece of blotting-paper on a basin of water and put a little lump of sodium on the blotting-paper, the sodium will catch fire and burn with a beautiful yellow flame.[1] A bit of sodium placed on your warm wet tongue would blaze up and cause a horrible burn, and the gas chlorine would most certainly kill you if you breathed it long enough. Yet when an atom of chlorine links hands with an atom of sodium, the result is a molecule of *sodium chloride*, or common salt, which is not only a wholesome substance, but one indispensable to life.

Compounds seldom bear any resemblance to the elements of which they are formed, but the molecule of a compound always has a definite relationship to the weights of its atoms. That is why the atomic weights, first pointed out by John Dalton, are so important in the wonderful magic of chemistry.

[1] The sodium really sets fire to the hydrogen in the water, and gets burnt itself in doing so.

Any molecule of any substance is exactly the weight of the combined weights of the atoms joined together to make it. The atomic weight of sodium is 23, that of chlorine is 35·5; so the weight of the salt molecule is 58·5. These weights show the chemist what proportions of the two elements must be combined to produce the *reaction* which makes salt. He knows that 23 ounces or pounds or tons of sodium, plus 35·5 ounces or pounds or tons of chlorine will produce exactly 58·5 ounces or pounds or tons of salt.

Once more let us return to our picture of the drilling boy and girl couples to which we likened the molecules of salt. There are millions and millions of these couples in the tiniest speck of salt you can see, and we will try to get an idea of what that means in proportion to things of which we know the size. Here is a little square □. Each of its sides measures one centimetre, and you know that if we give it a third equal dimension, so that it becomes an equal sided box, we can state its volume as 1 cubic centimetre. Well, in a cube of salt this size there are more than a million million million boy and girl couples arranged in orderly ranks and in layers one above the other, yet so spaced that they have plenty of room to swing their arms and legs and even their bodies, and they are all swinging and swaying and bobbing about without pause.

I am sure that to most of us a million million million conveys next to no meaning at all. It is quite impossible for imagination to grasp such figures, even when we try to approach them in easy stages. Still, we can, by comparison, get a general idea of how huge it is, and it is important that we should try to do so, for billions and trillions [1] are certain to find their way into our story, however care-

[1] A billion is a million million; a trillion is a million multiplied by itself twice, i.e. a million million million.

fully we try to avoid such numerical nightmares. Suppose we start by checking off in our minds a simple everyday number—say a thousand. Perhaps there are a thousand specimens in your stamp collection. If there are, you may well be proud of them, for a thousand stamps are really hard to come by. If you counted your stamps at the rate of one a second, it would take 16 minutes, 40 seconds. Ten thousand stamps would take $2\frac{3}{4}$ hours to count, supposing you could count continuously at the rate of one a second. A hundred thousand stamps would keep you busy for more than 27 hours. You would be tired by then, and rather hungry; but a hundred thousand is a mere nothing to the numbers atoms and molecules swarm in. The old grandfather clock, whose solemn tick-tock sounds the seconds, ticks off his millionth beat about every eleven days. When do you suppose he will reach his million millionth? If he starts now, he will reach it in about 30,000 years—if all goes well!

Looked at in this way, we see that a million is to a million million as eleven days to 30,000 years. But we must multiply our million again by a million to get a notion of the number of molecules in a cubic centimetre of salt. It is best to be frank with ourselves and admit that such numbers leave us entirely unimpressed because we cannot grasp them. So we will try another method by which we may get a rough picture to show us the size of molecules. We may imagine the tiniest grain of salt we can see with the naked eye, magnified until it is as large as an ordinary saloon car. If we could do that, we might see a molecule, for on that scale it would be about the size of a speck of dust.

And now here comes another question. What is the force that binds the atoms together to make molecules, and

holds the molecules together to make solids? To find the answer to that question you will have to explore an enormous territory in the great realm of physics, and when you have done so, and have put your question to all the other explorers you meet by the way, you may be able to tell *me* what the answer is. I don't think anybody knows for *certain* what this binding force is, except that it is electrical. Atoms are filled with electricity—I will tell you about this when we get to Chapter XV. However, we do know that it is this strange property of clinging together (it is called cohesion) that makes things hard. And it makes the same atoms group themselves so differently that they are easily mistaken for something else. As an example we may take a diamond and a lead pencil. There is nothing in the diamond but molecules of carbon, and there is nothing in graphite (which is the business part of the pencil) but molecules of carbon. Yet in the diamond the molecules cling together so tightly that it is one of the hardest substances known to us, while in the lead pencil the molecules are joined so loosely and part company so easily that we can transfer them to a piece of paper almost at a touch.

If you sit back in your chair now and think about what I have told you, your mind will probably seize at once upon the motion of the molecules as being the most remarkable thing about them. Those drilling boy and girl couples are typical of all matter in the *solid* state at *ordinary* temperatures. In salt, we chose a very simple molecule—one made by the union of two atoms. There is a great range of substances of which the molecules are made in this way by the union of a single atom of one element and a single atom of another. We must think of atoms as chummy little fellows having a great horror of loneliness. There are a few gases of which

the molecule and the atom are one and the same, that is to say the molecule consists of a single atom; and in the molecules of some metals, such as iron and gold, there is a solitary atom. But usually there are at least two atoms in the molecule. In most things the molecules are not like couples of simple boy and girl atoms; they are grouped in partnerships of all sorts of numbers of atoms, often very complicated partnerships. For example, the carbon atoms that (with hydrogen and nitrogen atoms) help to build up nearly all the substances belonging to the vegetable kingdom, cling together not in twos and threes but in groups of ten and more. Here, then, the drill—or the dance—that we may picture to be going on in every sort of matter, is no longer a drill of atoms in couples, but of atoms joined in quite large groups.

Still, molecules are always in motion. Perhaps you find it hard to realize that the regularly spaced particles, so infinitely tiny, that make this page, and the ink molecules of the print you are reading, are jumping up and down like so many fidgety boys. There is a very marvellous sort of motion going on in the internal structure of everything—a quivering or vibration of the particles that we can never see or feel or measure by direct means. Indirectly, however, we become aware of it through our senses; and we can even measure it indirectly—with a thermometer. This motion of the molecules is the secret of the strange property we call heat. It is something that must have excited your wonder over and over again, so we will give it a chapter all to itself.

CHAPTER V

The Dance of the Molecules

As we sit by the hearth on a winter evening and gaze upon the " pictures " in the fire; or as we watch the lid of the kettle jumping up and down, into our minds flashes the thought—what a wonderful thing heat is! I dare say you haven't read the last few pages very carefully; you have been skipping and thinking: " These atoms and molecules are a bit of a bore, and after all they can't matter to me!" But heat matters to you, I think you'll agree. It matters to every single thing that has life; it is one of the conditions that enable living things to exist. Well, it is the motion of atoms and molecules—their drilling—that gives to all matter the property of heat.

The easiest way of looking upon the hidden ways of nature is to follow the explorers who have cast light upon them. Men have always been puzzled by the mysterious thing heat, and even up to 200 years ago it was, in fact, pictured as a *thing*—a substance of some kind. In the eighteenth century there were two very famous men of science, named Henry Cavendish and Joseph Priestley, who helped to clear away much of the rubbishy nonsense taught by the alchemists. These men were born about thirty years before John Dalton, and in their day [1] it was still believed that fire was one of the four " elements ". They called it *phlogiston*, the Greek word for burning, and it was supposed to be a sort of matter that entered into things and set fire to them and mysteriously escaped in the flames.

[1] Henry Cavendish, born 1731, died 1810. Joseph Priestley, born 1733, died 1804.

These two men I have mentioned, Cavendish and Priestley, were both rather " odd ", but Cavendish was much the odder. He was the grandson of a duke and immensely rich, but he so hated the sight of his fellowmen and so hated to be spoken to, that he lived like a hermit—though he had two large houses in London and a magnificent library in another house—and he never spoke unless he was obliged to do so. Nevertheless he was an extraordinarily clever and clear-headed man who made many valuable discoveries. He discovered the lightest of the elements — hydrogen, and also found out that water was formed by the union of this element and another invisible gas. This other gas, oxygen, was discovered by Joseph Priestley. The eccentric Cavendish then studied heat, and soon began to doubt the existence of the mysterious *phlogiston*. But the discoverer of oxygen still held stoutly to the old theory. He called his newly discovered gas by a name that showed that he thought it was something from which the heat principle had been taken away. A good, round, full-bodied name it was too! He called it " dephlogisticated air "! Priestley was a dissenting minister of the sect called Unitarians, and although he was a great chemist, he was rather a difficult man to get on with owing to a habit of expressing what people thought were " daring " and sometimes stupid opinions on all sorts of subjects unconnected with science. One of the keenest students of Priestley's work in chemistry was the great French chemist Lavoisier. Priestley showed Lavoisier how


Joseph Priestley

to make oxygen, and Lavoisier startled the world of science by proving that all forms of burning were due to the oxygen of the air entering into combination with the burning substance. Thus the bottom was knocked out of the old phlogiston idea, but lots of people were still unconvinced — Priestley among them.

Henry Cavendish

I have told you about these men because I want you to realize that it is but a very short while since the dawning of the exact scientific knowledge of our own day. Our understanding of the true nature of heat did not come until after Priestley, Cavendish, and Lavoisier were dead, though they were surprising the world with their discoveries less than 150 years ago. While Priestley was stoutly defending the non-existent substance phlogiston, James Watt was struggling to perfect his steam engine. He was bringing into being a form of power that was to change the ways and the habits of men throughout the world. The steam engine is a *heat* engine; it derives its power from the motion of the molecules in burning coal or oil or other fuel. This molecular motion is taken up by the water converted into steam, and so transmitted to a piston, or to the blades of a turbine. It is the fact that molecules possess motion that gives us *energy*. It is the source of all our power, whether in our bodies or our engines. We can use it in a hundred different ways, sometimes making it drive trains and ships, and motor-cars and aeroplanes; or making it provide us with soap and

candles and bread and meat and ice-cream, or things like wireless and X-rays.

In solid substances (substances that have a definite shape) the molecules are so close together that they can never move far from a fixed spot, and in this state their motion is a vibration or trembling. But as soon as anything happens to excite them to quicker movement the substance becomes warmer. Perhaps you can think of some of the ways in which we can make molecules dance faster. If you rub two sticks together—or your hands—they become warmer. If you rubbed the sticks fast enough you could boil water; rub them faster still and they will catch fire. Very probably that was the way in which primitive man obtained fire. We get our fire nowadays by a combination of friction and chemical action. When we strike a match, the rubbing excites the molecules of the chemical composition to dance so fast that the groups let go their hands and the atoms rush off to find new partners.

One of the results of chemical change is the transfer of heat from one substance to another. We might think that when we strike a match, or light a fire, we are *creating* heat. But that is something we can never do, for heat is a form of energy. It is a property of matter, and all that we can do is to apply it to our needs—such as directing it to give us bodily warmth through food or clothing, so that we can transfer the energy through our muscles to building houses or playing cricket; or through machinery to perform tasks beyond the strength of our muscles. We can never add a single atom to the matter already in the world, nor can we really destroy matter, though little bits may be chipped off the atoms of some of the elements.

There are lots of ways in which the molecules in things can be excited to dance fast and thus liberate the energy of

their heat motion. In a burning fire there is a terrific dance. While they were in the coal cellar the molecules in the lumps of coal were vibrating happily among themselves. Almost as soon as the scuttle was filled the vibrations grew quicker, for the molecules in the warmer air around them passed on to them some of their heat motion. Now that the coal has been in the warm room all day, the coal molecules, like the air molecules, have become very merry indeed. Their drilling is so violent that they need more room, so they move farther apart. I think you can see what the result must be; the lumps of coal *become larger*. I am sure you know that things expand as they become warmer.

When we put the coal on the fire, the violent movement of the molecules becomes still more violent. In a short while they leave their nice orderly ranks and charge about in all directions. Then the atoms forming them break away to join hands with the oxygen atoms in the air. Part of the coal changes to liquid, the bubbling tarry stuff you jab at with the poker; and part of it becomes gas, which combines so eagerly with the oxygen that the motion of the molecules becomes apparent not only to the nerves of the skin, which tell us that it is heat, but to the nerves of our eyes, which tell us that it is light as well. We can see by it. Here is another form of energy, or rather, the same form of energy producing a different effect.

I am sure you know that matter exists in three forms; as a solid, a liquid, or a gas. If the world were hot enough, all the elements would exist as gases; there would be no solids or liquids. If it were cold enough, everything in it would be solid. To take a view a little less drastic, if the temperature everywhere on earth was below freezing, there would not be any water, but only ice; while if it was above boiling-point there still would not be any water, but only

steam. What is it that makes the difference between the three states of the same substance? Well, thinking of what we know of water, of our own experience, we should answer —heat. A much better answer is the fight that goes on between the force that holds the molecules together and the energy of their motion that drives them apart. In a solid substance the molecules are content to hold hands and go through their drill, as we saw in our grain of salt. If we heat the salt to melting-point, the heat motion of the molecules drives them farther and farther apart until their neat orderly ranks—the crystal lattices—are broken up in confusion, and the molecules abandon their drill and engage in a rough and tumble dance. Of course, they take up more room, so the liquid is less dense than the solid; in other words, the same amount of matter is expanded in a greater volume.[1]

Although the change from the solid to the liquid state is the result of the faster motion of the molecules, there is not really very much difference in the space they take up. But if their motion is speeded up to the point at which they become gas, why then, hey-presto! a most astonishing change comes about. The energy of their motion so far overcomes the force that holds them together in the solid and liquid states that the molecules can dart about in all directions. There is an enormous expansion. When a given quantity of water is turned into steam, the molecules occupy 1630 times as much room as they took up when in the form of water.

In any gas the particles are charging this way and that like so many millions of tiny bullets. They go at a terrific speed, something like a mile in 4 seconds—15 miles a

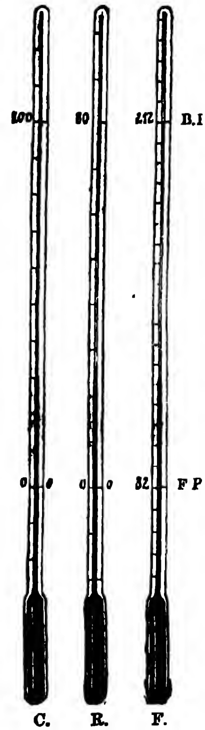
[1] There are some remarkable exceptions to this rule. Ice is less dense than water—it floats. It occupies more room than the water, which is why freezing water-pipes burst. Molten iron and bismuth also take up more room in the solid state than the liquid state. This property of bismuth makes it a very useful ingredient of type metal, it expands as it solidifies, and so forces itself into all parts of the mould.

minute. They often collide with each other, but for the most part there is so much "clear space" between them that the molecules come to the end of their journey only when they hit the walls of the vessel enclosing them; our lungs, say, or gas pipes or lemonade bottles or motor tyres. Then they bounce back and start a new journey in another direction. It is this constant "bombardment" by uncountable billions of swiftly moving molecules that we call the *pressure* of gases. It sometimes happens that too many molecules become enclosed in a vessel not strong enough to withstand their battering or bombardment. The vessel suddenly gives way and we have an explosion.

I have a feeling that somebody wants to ask a question. Somebody is puzzled to know why the heat motion of the molecules doesn't make all gases hot. The answer is that it does—compared with the solid or liquid states of the same molecules. The air is very hot indeed, compared with liquid air, which has a boiling-point (i.e. the temperature at which it changes from the liquid to the gaseous state) of 190° below zero on the Centigrade scale.[1] Still, liquid air is a warm substance compared with liquid hydrogen, which has a temperature of 250° below zero Centigrade. Some substances are very reluctant to change their states; we can say that in such case only very violent dancing of the molecules can overcome the force that holds them to one another. You know that water changes very easily, for a range of no more than 100° C. turns ice into steam. The metal mercury is a liquid at ordinary temperatures—the temperatures within which living things can exist—but it does not take much cold to freeze it, nor much heat to boil it. On the other hand, copper, a solid at ordinary

[1] A comparison of the Centigrade and Fahrenheit scales of thermometers is given on p. 61.

Name.	Freezing-point.	Boiling-point.	Number of divisions between freezing- and boiling-points.
Centigrade	0°	100°	100
Réaumur	0°	80°	80
Fahrenheit	32°	212°	180



Comparison of Centigrade, Réaumur, and Fahrenheit Scales

temperatures, does not melt below 1000° C., while a temperature of 2310° C. is needed to turn it into gas.

Here are a few simple substances set out with their melting-points (at which the solid changes to liquid), and their boiling-points (at which the liquid changes into gas), so that you can easily compare them. I may mention that a red-hot poker has a temperature of 500° C., roughly:

		Melting-point	*Boiling-point*
Water ..	..	0°	100°
Mercury	..	−39°	357°
Copper	..	1080°	2310°
Oxygen	..	−219°	−183°

Somebody else is puzzling over what I said about the speed of molecules. He wants to know how fast they can dash about if they get hot enough. Well, if he thinks about this I think he will soon see that however fast they go, they may yet go faster; however hot they are, they may yet be hotter. The earth is only a very small affair, and the little bits of matter of which it is made are really very tiny. The heat energy of these tiny bits is soon exchanged, handed over to other tiny bits, as when the heat of a fire passes into the air of the room and into walls, pictures, books, people—whatever is in the room. But in the vast masses of the sun and distant stars the heat energy is terrific and the temperature must be measured in millions of degrees. We cannot put a limit to hotness. Nor to coldness, do you think? Think again. If heat is the form of energy due to the motion of molecules, what happens when there is *no* motion? Clearly, no heat. It is believed that all molecules are absolutely still at a temperature of 273° C. below the melting-point of ice. This is called the absolute zero of temperature. Nothing can ever be colder.

CHAPTER VI

A Talk about Light

There was a very jolly party on the shore the other day. Everyone enjoyed it. They soaked themselves in the sea and in the sunshine; and bathing, basking, paddling, playing games, scrambling about the rocks and the cliffs, this happy party made the most of a glorious holiday.

They talked about all sorts of things, naturally. If anyone had said to them at the end of the day: " What did you talk about?" most of them might have been hard put to it to remember any of the subjects that had been discussed, they were such very ordinary ones. But of course one or two of those who were there remembered particular things. We might " listen in " to snatches of their talk.

" I can't think how people run their houses without electricity. In Tasmania we use it for everything, but of course it is very cheap, for there is any amount of water power."

" As I foretold it would be, that wireless of yours is a bit of a nuisance, Dick. I can't think why you wanted to bring it. Anyhow, no one wants to listen to jazz now, so switch it off or else take it where we can't hear it."

" You know, there was something the matter with her foot—it was just the tiniest bit the wrong shape—so she could never get shoes that fitted comfortably. But we took her to that new shop; and what do you think? They've made shoes that fit perfectly. They X-rayed her feet with the shoes on, so that they could see exactly where they were wrong."

" Our snapshots ought to come out well because the light is so good to-day."

"Poor Aunt Lucy must be terribly hot in her dark dress. John always says it doesn't make much difference, because although dark things absorb heat more readily than light colours, they also part with it more quickly. He says that because of this we ought to wear white clothes in winter as well as in summer, because they hold the heat better."

"You children ought to put your clothes on now. Large doses of ultra-violet rays do more harm than good, when you aren't used to them."

"The infra-red photographs show everything quite clearly over a far wider stretch of country than it is possible to photograph by ordinary light. The reason is, of course, that infra-red rays are not scattered so much by dust and moisture in the air."

"Of course."

"It will be cold going home."

"And dark. There's no moon."

And so on. They talked about any number of other things. Perhaps you think we might have listened-in to more interesting bits. It was rather ordinary talk, wasn't it? "It is very hot—it will be cold. Electricity is useful; photography is a nice hobby; we are getting sunburnt; Aunt Amy's eyes are tired." Just like a French exercise.

However, there is something very interesting about the bits I have recorded from the small-talk of that picnic party. Quite a large part of it was taken up with the subject of *radiant energy*. You see, it was the same subject, though it presented itself in many different appearances. This radiant energy is something that rather resembles the disguises put on by a clever actor. The actor may appear before us in half a dozen different characters in which his dress and make-up might completely mislead us into thinking that each character was played by a separate actor, if we had

E 712

SUPERSPEED PHOTOGRAPHY

Exposures of $\frac{1}{75000}$ of a second. The top photograph shows a cup of coffee breaking as it touches the floor. In doing so it makes an electric contact which causes a spark by the light of which the photograph was taken. The lower picture shows the washing of a milk bottle. Photographs by K. G. Germeshausen and H. E. Edgerton.

no means of proving that each character was really presented by the same actor. So it is with the appearances of the property of matter which we call radiant energy. The same matter exhibits forms of the same energy that affect us in such different ways, that it is only within the lifetime of people still living that science has succeeded in identifying these many forms for what they really are. Light, heat, electricity and magnetism, the different sorts of rays called X-rays, ultra-violet rays, and infra-red rays are not separate "things" but the separate characters or *effects* of the mysterious property called energy.

In the last chapter we saw that heat is an effect depending on the vigour with which the minute particles of matter dance about. We know that when they dance fast enough they may give us light as well as heat. Whenever we make light for ourselves, candle-light or electric-light or any other sort, we can only obtain it by "gingering-up" the atoms of matter to the point at which they give out the right sort of energy that acts on our eyes. A great deal of it is wasted energy taking the form of heat. When we want light only, it is disappointing to have to do a good deal of extra work in producing heat as well, but we have not yet discovered how to save ourselves the extra work. Yet the glow-worm and the fire-fly have discovered it, and the far more lowly microscopic creatures that give phosphorescence [1] to sea-water and to stale fish—their light is very nearly all within the range of human vision, whereas our very best electric lamps give only a tenth of the energy supplied to them as visible radiation. Nine-tenths of the total energy takes the form of *invisible* radiation. There is a splendid gift to humanity—and a fortune—awaiting whomever can solve

[1] It has nothing to do with phosphorus. The light emitted by living organisms is properly called *bio-luminescence*.

Glow-worms are small beetles that have discovered the secret of making light without heat They feed chiefly on snails, and may be found on the grass about banks and ditches on warm nights in late summer The female insects are without wings and are more luminous than the winged males. The luminous substances are carried on the abdomen, which is provided with great numbers of little air-passages for supplying the oxygen necessary for combustion

the glow-worm's secret of "cold" light. Why not start hunting for it, straight away? Any chemist will tell you what substances the glow-worm burns to make his mysterious light; what you must find out is his method of burning them.

I hope you have noticed that in pointing out to you the wasteful nature of our light-making, compared with the glow-worm's, I have used words intended to show that light and heat are not different things, but different degrees of the same thing. Light is the energy of *visible* radiation, but the same energy is also radiated in many forms of *invisible*

radiation, those that we cannot see. They are invisible because the nerves which telegraph the light impulses to our brains are insensitive to them. We talk about "seeing light", but we can no more see light than we can see electricity or heat or wireless-rays. People frequently regard light as a kind of "stuff" which issues from its source, the sun, say, or a bonfire, and streams through space like the illuminated beam from a lighthouse or a motor head-light. Actually, however, light is invisible until it is reflected from the surface of an object placed in its path. When you see a sunbeam coming into a darkened room through a chink in the curtains you are not seeing light, but the illuminated particles of dust and moisture lying in the path of the rays that stream through the chink. The particles reflect some of these rays to your eyes, so that you become aware of the reflection as a lighted object. The rays themselves are not visible. There is a very simple way of demonstrating that light does not produce any visible effect until it encounters some object; it is to pass a beam of light through a black box from which the air (and with it the dust and moisture which it always carries) has been carefully extracted. You can see into the box through a window, but the light can only be seen entering the slit in one side of the box and leaving it by a slit in the opposite side. The inside of the box remains completely dark. If we could go outside the earth's atmosphere at midday we should find ourselves in midnight darkness. Our eyes would intercept some of the rays coming from the sun and the stars, and we should see them just as we do at present. We should also see ourselves and the earth and the moon by the rays reflected from their surfaces, but all around us would be as black as night, though the rays of light would be streaming past us in every direction.

It used to be thought that light was composed of tiny particles of matter that were shot out from a burning source; it was thought that some of these particles entered our eyes and so made us aware of them. The great Sir Isaac Newton, wisest and ablest of all the splendid captains who have guided the ship of science, thought that light might be some such stream of minute particles or "corpuscles". He did not say it was, mind, for he was unable to prove it; but he put forward a number of reasons why it might be so. Long before Newton's time—he was born in 1642 and died in 1727—other thinkers had suggested that light was not a substantial thing made up of corpuscles but a wave-like motion, a system of vibrations, set going in some mysterious way in an invisible, intangible material connecting everything. This mysterious substance was the ether.[1]

We now know, without any doubt, that light *is* a wave-motion, and that the like forms of energy, such as heat, X-rays, and electricity are also waves or vibrations set going in the ether. Whenever the atoms of the elements are suitably excited—made to dance to the right tune, we may say—the energy they set free makes a "splash in the ether". Just what that means, I hope to be able to explain when we come to grips with electricity; for the moment let us look at some of the ways in which light behaves.

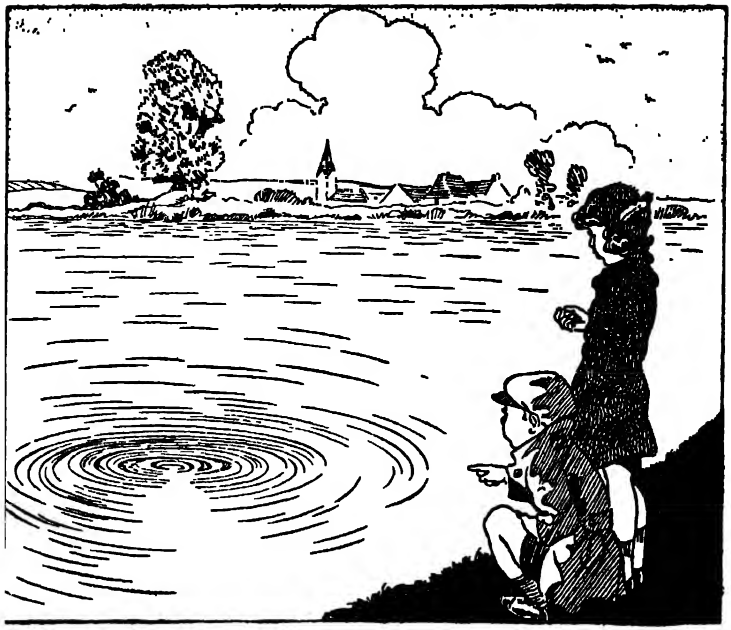
First of all, we know that light is something that can travel across vast distances of empty space. It comes to us from the sun, which is 92,000,000 miles away, and from far remoter sources. For wherever we can see a star, from thence light must be coming to our eyes. Now, you will agree that it is a truly remarkable property of this energy to be able to travel through millions and millions of miles

[1] Sometimes spelt æther (*Greek*, "to light"). The ether of space must not be confused with the ether of chemistry, which is a very volatile liquid made from alcohol.

of *empty* space. I am sure that you know that space is utterly and completely empty, in between the stars and the planets and their moons, or satellites. The earth's atmosphere is a very marvellous cloak protecting the living world; but it is a very thin one. Less than 200 miles outside us there is nothingness; no more atoms and molecules nearer than the moon, if we leave out of account the streams of tiny bodies, made of iron and nickel, that are always getting in the earth's way.[1]

Clearly, therefore, the wave-motion of light is something very different from the other sorts of waves known to us, which all need some material substance in which to travel; we are familiar with waves in water and other liquids; with earthquake waves, with waves in steel girders, even in wooden girders, like floor joists—they tremble if they are strained enough. Waves in air, striking our eardrums, make us aware of them as sounds, musical or otherwise. But all these waves are disturbances of matter, surgings of atoms and molecules of the substances I have mentioned, in response to *strain*. There is always an exchange of energy in every kind of strain. If you throw a stone into a pond, some of your own heat-energy goes into the ripples you set up, each wavelet carrying a tiny part of it, so that it is able to rise up against the force of gravity pulling it to the centre of the earth. It can lift a stick or a toy boat up with it. When the wavelets reach the edge of the pond they hand over what is left of the heat-energy you gave them to the bank. You know that energy is never lost, and you can see the cycle of events; you have parted with a little energy—and a little weight; the pond has received your energy (and weight) and transmitted them as energy of wave-

[1] These are meteors, mostly about the size of peas or small pebbles, and the earth pulls millions of them to itself every day. The largest of them become visible as "shooting-stars" when they hit the atmosphere.



Making Waves in Water

motion in the water to the bank. It has made the bank a trifle hotter and heavier than it was before the wave-motion reached it. It is exactly the same when you whisper: a little of your energy sets up ripples in the air that eventually reach somebody's ears and surrender their energy again in making them hotter and heavier. Those are very, very trifling examples of the way in which matter is pulled and pushed and strained this way and that and made to transmit energy. A big enough water-wave smashes ships and devastates coasts, and there is then no doubt about its pressure—its weight.

I want you to understand that light waves and wireless waves—all forms of radiant energy—resemble all other kinds

of waves, all other forms of energy, in this; they exert pressure. Just as a water wave or an air wave has *weight*, so have radiant energy waves. You could knock a man down with a searchlight—if you could discover how to make one powerful enough! In actual fact, the weight of light is infinitely small, so small that its measurement ranks as one of the greatest triumphs of modern science. It has been estimated that the weight of the energy radiated by the sun is about 4,000,000 tons a second. Of this prodigious amount only a very small proportion reaches the earth. Yet sunlight exerts on the earth a steady pressure equal to the weight of some 70,000 tons. This radiant energy, on which the life of earth depends, is a most mysterious thing. Light is a form of energy set free by atoms whenever particular things happen to them. I will tell you what is believed to happen in Chapter XV. The energy travels outwards in all directions in jerks or gusts that make waves much like the waves you can make by beating the surface of water with a piece of wood or by letting a handful of pebbles fall in, one by one. When the waves encounter matter of any kind, the matter responds; it reacts to the influence according to how its atoms are arranged, absorbing the energy and storing it for future use or else passing it on immediately to agitate other atoms.

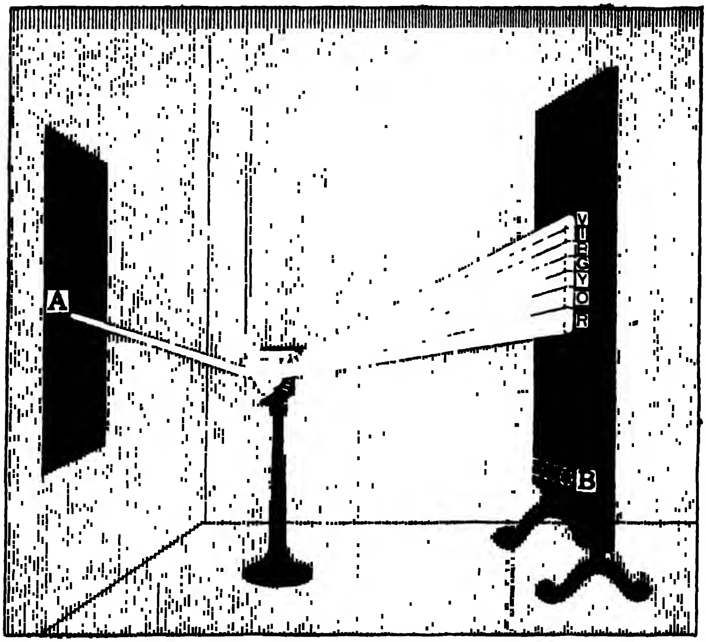
That is not difficult to understand. What puzzles us is to know how the waves travel in empty space! We cannot imagine waves without something to make them in. It was to get over the difficulty of "waves in nothingness" that the ether of space was invented.[1] The ether is supposed

[1] More strictly speaking, the idea of ether is much older than any theory of the wave-motion of light. It is just as hard to understand how the heavenly bodies are held in their courses unless there is some very substantial substance for them to "swim in". The moon is tethered to the earth and together they waltz round the sun at a speed of 1000 miles a minute. It is impossible to conceive a tether made of *nothing* or to suppose that gravity can act without a medium to act *through*.

to be some substance that fills all space throughout the universe, passing through and around all the matter contained therein. The atoms are floating in ether; and if we remove the atoms from something within our reach—say, if we pump all the air out of a vessel—there is just as much ether there as there ever was. Perhaps, but we don't need to worry our heads about it. The ether may be there or it may not; it cannot be proved, one way or the other, and science is only concerned with facts—things that *can* be proved. It therefore tells us that light travels across empty space, but that there is no means—as yet—of knowing how it travels. We are all apt to talk much too glibly about the ether without understanding that it is not weighable or measureable or demonstrable in any physical sense whatever. It is what is called a *convention*, that is, a thing agreed upon; in this case an *idea* of something that helps us to picture that which we could not otherwise understand.

We do *not* know how light travels. But we do know how fast it travels. Its velocity was first found out, many years ago, by timing the eclipses of Jupiter's moons when they were nearest to the earth, and when they were farthest away. In more recent times other ways have been used to check the result of the astronomical method. Two famous French scientists named Foucault[1] and Fizeau measured the speed of light by very ingenious devices. They sent a beam of light from one mirror to another distant mirror and then back again to the first mirror, which had meanwhile been slightly rotated. They found the speed of light to be 186,600 miles a second—a result not greatly differing from the results obtained by other methods. Light goes just about a million times faster than sound. When you

[1] Jean Bernard Léon Foucault, born 1819, died 1868, also performed a celebrated experiment with a pendulum suspended from the roof of a lofty building to prove that the earth revolves.



Obtaining the Solar Spectrum by Newton's Method

A beam of sunlight is admitted through a small opening at A. A prism is placed in its path. The beam is deflected upwards and at the same time resolved into a number of different colours forming what is called the solar spectrum. AB shows the track of the beam of light if no prism was placed in its path.

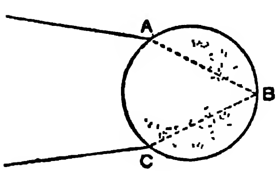
look up at the sun, you see it as it was eight minutes beforehand, for its light has taken that long to reach your eyes. The moon is very close to us, and so its light only takes 1⅕ seconds to come to us. But the light of the *nearest* of the stars[1] has to travel at this terrific speed for four and a quarter years before it reaches the earth.

I am sure you know that ordinary light—" white light ", as we call it—is really a mixture of lights of different colours. It was Sir Isaac Newton who first showed how easily the colours can be separated out into a continuous band, called

[1] Proxima Centauri. It is 25 million million miles away.

the *spectrum.* Newton *bent* a ray of light by passing it through a prism. A prism is simply a triangular-shaped piece of solid glass. You must have seen the spectrum when it has been thrown by accident on wall or ceiling by light which was bent in falling on the bevelled edge of a mirror, or perhaps on a cut glass salt-cellar, or an ornament. It is the fact that light is always bent when it passes from one medium to another, as from air to glass, that makes possible the wonderful inventions that have enabled us to harness it —fascinating bits of glass that we will look into in the next chapter. At the moment, we must attend to Newton and the spectrum.

The sketch on page 73 shows what he did. He allowed a narrow beam of sunlight to enter a dark room through a little hole in a shutter. In the path of the beam of light he placed a prism of glass which bent the beam out of the straight course it would have followed if the prism had not been there. The line AB shows the direct course of



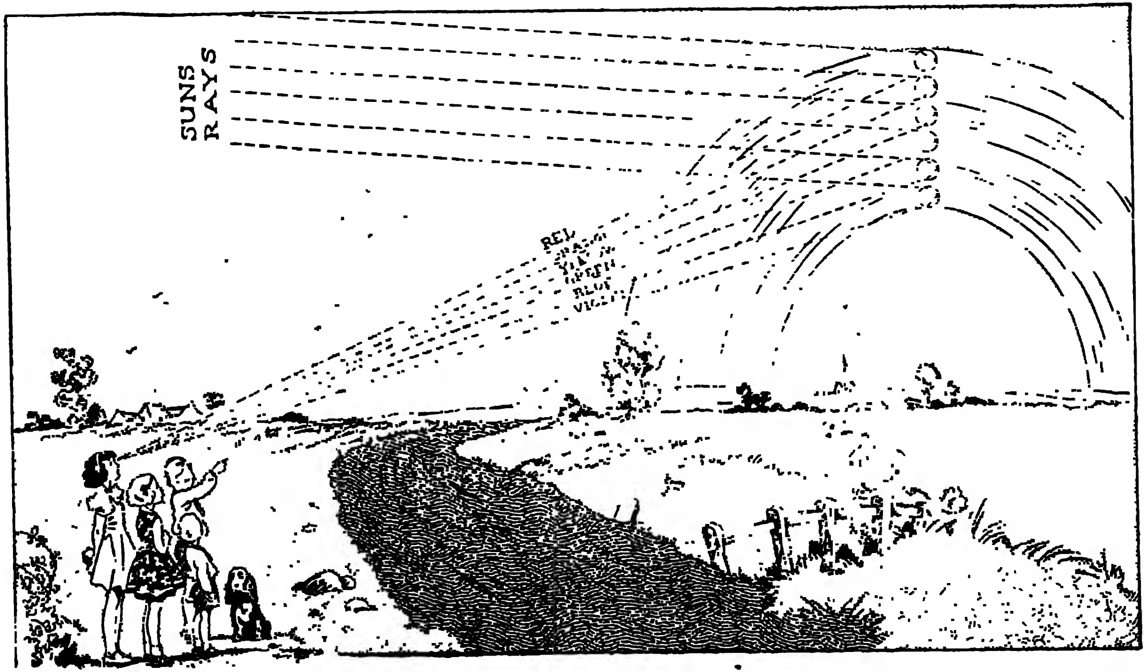
the light (you must remember that light always travels in straight lines [1]), and you see how the prism bends the rays and so spreads them out into the coloured spectrum. The colours we can see in the spectrum of sunlight are red, orange, yellow, green, blue, indigo, and violet. Now, why should a glass prism turn white light into this beautiful ribbon of many colours? We see the same ribbon in a rainbow, yet there are no glass prisms there. True; but every raindrop is something more than a prism—it is a mirror as well. Each raindrop reflects to us an image of the sun, so in a rainbow we see myriads and myriads of tiny suns. The figure shows what is happening to the light

[1] In certain very peculiar conditions it seems able to bend round corners.

in each raindrop. The ray of light enters it at A and is bent so that it strikes the opposite surface of the drop at B. B reflects it to C, where it passes again into the air, again becoming bent in leaving the drop, just as it was bent in entering it. From C the ray travels to our eyes. It brings with it its picture of the sun, or rather, that particular *part* of the picture which has been bent to the correct angle to enable it to reach our eyes.

Recollect how you have tormented a friend by flashing a piece of looking-glass or a piece of bright tin. It was not very easy to get the glass in just the one and *only* position in which the light was reflected to the particular spot you wished to reach—your friend's nose, perhaps. The light from your mirror danced here and there, and it was hard to stick to the correct angle even when you had found it. It is the same with the rainbow. There is a moment in the descent of the raindrops when some of them are in exactly the right positions to reflect the light at the right angle at which it can reach us.

But where do the colours come from? They come because the rays of sunlight are bent just as they are in Newton's prism. If you look again at the sketch (p. 73) you will see that the light coming through the prism is bent *unequally*. The violet rays are bent much more sharply than the red. All the light that goes into the prism comes out again; it is all in the spectrum. And all the light that goes into the raindrops is reflected again, but it comes out at varying angles, because it is bent unequally. If you think hard about this you will come to see that there must be a particular position (or set of positions) for yourself, the sun, and the raindrops, in which only the rays that are bent to the angles peculiar to certain colours are visible to you. The other rays are there, of course, but they pass by you,



Why the rainbow is seen. Read the text on page 75 and look at the diagram on page 74 and you will understand the picture above. Of course the raindrops are shown much too large. All the colour rays of the spectrum are coming from each drop, but each ray is bent at a different angle and all but one passes by the eye. You should realise from this diagram that no two people see the same rainbow.

being bent to different angles. But the rain is falling in a curtain before you, and light is therefore reflected to you from *all* the angles comprising the spectrum. You see the violet rays at the bottom of the bow because these rays emerge from the raindrops at the flattest angle; and the red rays at the highest part of the bow because they are reflected at a sharper angle.[1] You can only see a rainbow when the bright sun is rather low in the sky, for if he is higher than 40 degrees from the horizon the necessary angles cannot be obtained. You cannot find the spot where the rainbow ends, and you cannot walk under a rainbow. I think I have said enough to explain why.

All light, whatever the source it comes from, is a blend of different colours, and can be spread out and analysed by its spectrum.[2] The instrument by which this is done is called a *spectroscope*. It is a very beautiful instrument that bears little outward resemblance to Newton's prism and dark chamber, though it is the same in principle. It is one of the most useful "tools" of science. By its use astronomers can tell us what atoms the stars are made of, and spectrum analysis greatly helps the chemist and physicist to probe the nature and to understand the properties of the everyday world around us. I shall have more to tell you about the spectrum in Chapter X.

I dare say you are thinking: this is all very well. Everyone knows that white light goes into a prism and comes out in colours. But what *are* the colours? Where do they come from? How do they get into the light to begin with? I agree that we ought to try to find answers to such very important questions, yet I am not sure that you will understand the

[1] Observant readers will perhaps notice that, in the rainbow, the angles made by the different colours appear in reverse order to that shown on p. 73. The explanation lies in the fact that in the raindrops light is twice bent and reflected as well. It is a fairly straightforward problem in the measurement of angles.

[2] Plural, spectra.

answers until you have read a great deal more about radiant energy than I can possibly tell you here. But at least we can try to get on the right road.

First of all, it is necessary to realize that colour is a sensation within ourselves. Outside ourselves there are only the waves of energy sent out by the source of the light, as I tried to make clear earlier in this chapter. These waves

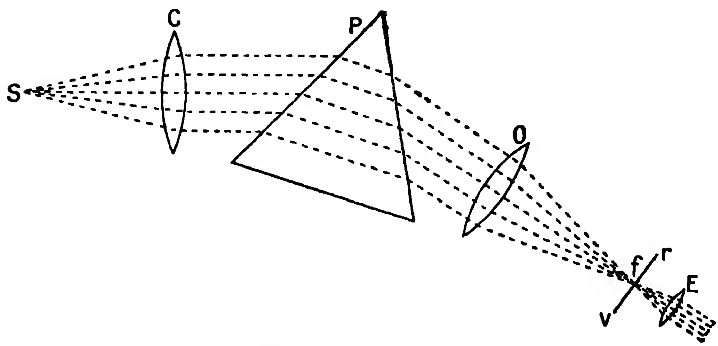
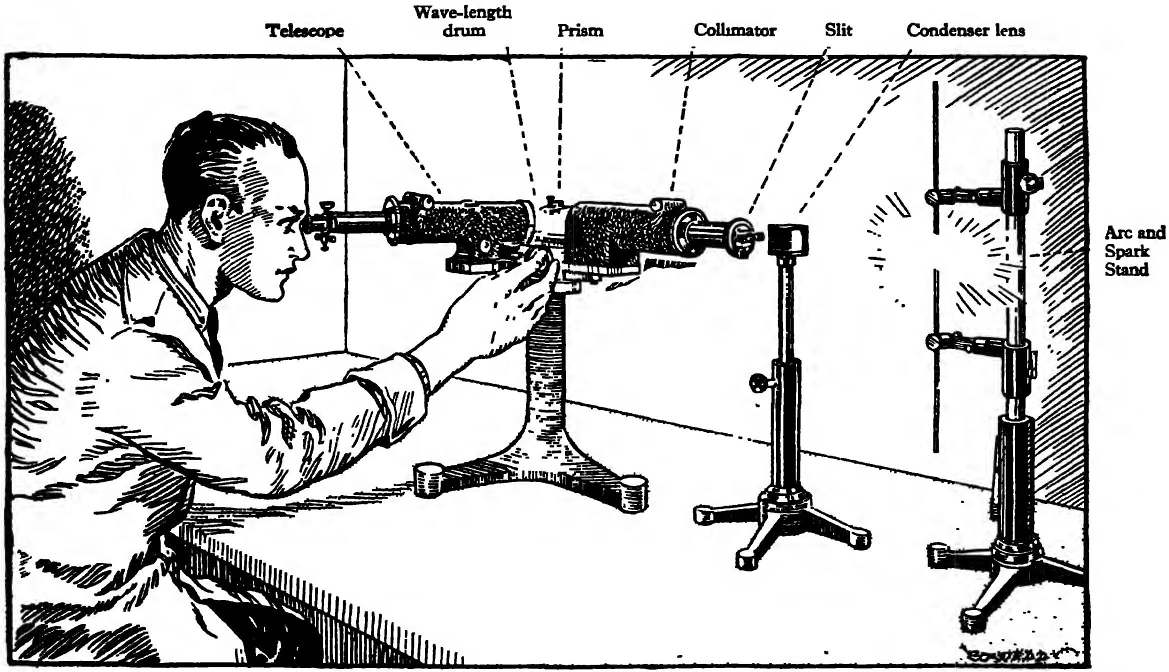


Diagram showing the arrangement of the Spectroscope

S, Slit. C, Collimating lens which makes the rays parallel. P, Prism. O, Object-glass of telescope E, Eye-piece. *f*, Image of slit. *v*, Violet end of spectrum. *r*, Red end of spectrum.

are the same in kind but very different in degree, in quality. You can make quite a lot of different qualities of waves on the surface of a pond. You can disturb it so as to send out *short* waves if you beat it quickly with your hands in imitation of a paddle-wheel; or you can send out *long* waves if you push a wooden box, or any sort of float, slowly to and fro. Your waves are a form of energy (we went into this on p. 69) and the atoms in any source of light are sending out little regular squirts of energy in much the same way as you can on the pond. The waves set up by these " light-squirts " are of many different sizes and qualities, of which only a very few find any response from our eyes. In other words, our vision depends on the waves of a particular



A SCIENTIST USING A SPECTROSCOPE

His right hand is adjusting the wave-length drum. This drawing was made under the supervision of Messrs. Adam Hilger Ltd., the makers of the spectroscope

size and frequency. The size of a wave is the distance from one crest and the next. This is called its *wave-length*. The *frequency* is the name given to the number of complete waves that pass any given point in a second.

I want you to remember that all the waves travel at the same speed of 186,600 miles a second. The short waves get to their destination just as soon as the long waves, but in doing so they must "bob up and down" much more quickly. It is certain that the shorter the wave the greater its frequency must be. Our colour sensations are the result of the way in which the nerves in our eyes answer the different sorts of signals sent out by the light-squirts.

We might picture what happens in this way. The light-squirts issue from the source in waves of energy of different frequencies. They travel outwards in all directions and bump up against the objects in their paths. These objects either absorb the energy, much as the buffers of a railway carriage absorb and store up the energy of sudden blows in shunting, or as the springs of a motor-car absorb and store up the blows of a rough road; or else they reflect the energy, sending it out again like an echo. The waves that are echoed from an object come to our eyes and batter them with a hail of infinitesimally tiny blows. It is this hail of blows that makes us see the object. Further, it makes us aware of the particular wave-lengths (or frequencies) that have dealt the blows by showing us a particular and distinctive colour.

Ordinary light is a mixture of energy squirts of many different wave-lengths; whether they are all reflected or not depends on the nature of the atoms in the objects they bump against. An object looks white because it reflects all—or nearly all—the light rays [1] that can affect our eyes. A black

[1] Perhaps you wonder how a wave can be a ray. A ray is in reality only a convenient way of dividing up all the light that comes from an object. See p. 85.

object or black pattern is something we cannot see (unless it has a curved highly polished surface), because it absorbs all the visible wave-lengths—and very nice it often looks! You don't *see* the type on this page; what you are really aware of is a great number of gaps, of recognizable shapes, where light is not reflected. Whatever colour we see, we may know that it is sending to our eyes light of a definite wave-length, or combination of wave-lengths. A red object reflects only the red wave-lengths and absorbs the others; a green object only the green wave-lengths, and so on.

Colour plays an immensely important part in our lives. I need not remind you how much it adds to our happiness. But just think how sad you would be if you were suddenly cut off from enjoyment of the lovely colours with which Nature has so lavishly painted the world! We ought to resolve never to do anything to diminish colour, but to add to it whenever we can, especially in our towns, which are generally much too drab and dingy. We must be very careful, though, how we use our paint brushes, for the wrong colours, or colour in the wrong place, can be as saddening as absence of colour; nearly as bad for us, but, perhaps, not quite. We are always safe when we use flowers and trees and grass, for we can use these living paint pots without fear of hurting anybody's colour sense. Yet, whether the colour is a direct gift from Nature, as in a petal or a butterfly wing, or a gift of modern science, as when it comes from a paint-maker or a dye-works, it is all a matter of the wave-lengths of different pulses of energy—different strengths of light-squirts.

To help you to grasp the vibratory nature of light—its wave-like nature—I have used the illustration of ripples made on a pond. It was all very well as a rough guide, but there is no really accurate picture that can be used.

For one thing our water-ripples travel only in a horizontal direction; they are confined to one plane, that of the surface of the water. The waves shot out by excited atoms go forth in all directions and at every angle.

And again, the most delicate wave we can imagine would be a gigantic thing compared with the largest light wave, which is the red wave. Red light has a wave-length of 3/100,000 of an inch; violet light only half this wave-length. Red light has a frequency of over 400 million million; that number of complete waves passes a given point in a second. But when you look at a violet 800 million million waves must enter your eyes every second.

No one can make much sense of figures like those. *But they have been measured!* Does not that thought convey to you a fuller understanding of the true splendour of scientific achievement? The waves are sorted out in a kind of sieve called a " diffraction grating ". And now we must see how light has been harnessed. But don't think you have finished with waves. The world is kept going by waves of radiant energy, of one sort and another, and explorers of science bump into them at almost every turn.

CHAPTER VII

Light in Harness

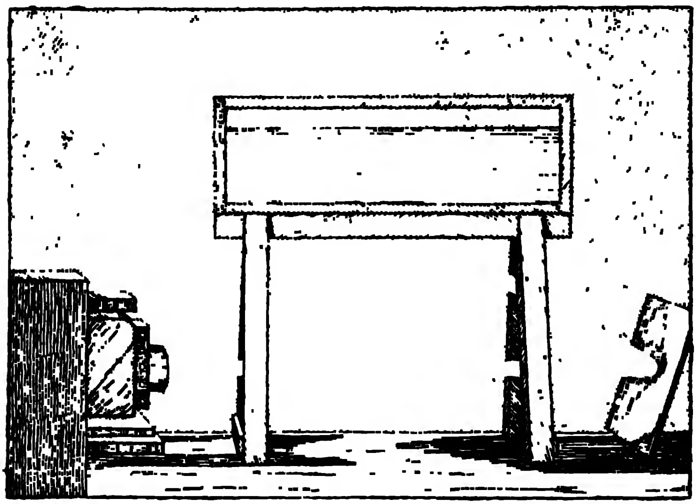
People are rather fond of talking about harnessing some force or other—steam, gas, water, electricity; horses, sometimes. We say that we have harnessed a thing whenever we have so brought it under control that we can bend it to our will. Now, of all the things we can thus bend and force

to our service, light is the only one that is really and truly bent, in the way that we can bend a bit of wire. And we must include with light not only the waves set up by the "squirts" of radiant energy that enable us to see, but the invisible wave-lengths as well; X-rays and wireless waves; ultra-violet and infra-red rays—they can all be bent and turned from one straight path into another straight path, according to laws that were very exactly worked out many years ago. These laws governing the bending of light are the foundation of the very important science of optics.

It is a very good thing for us that opticians know how to bend light, for if they had not found out, there would not be any spectacles or "field-glasses" or binoculars, or telescopes, or instruments like sextants and theodolites, or microscopes, or spectroscopes, stereoscopes, periscopes or any other sort of "scope". All these words ending in "scope" come from the Greek verb *skopein*, to see. A telescope is an instrument enabling us to see *at a distance*; a microscope helps us to see small things; a spectroscope to see the spectrum; in the stereoscope we see photographs as if they stood out—the scenes look solid. Periscope means *to see about*; it shows things quite outside the observer's natural line of vision. There are lots of other scopes. I always think the least appropriately named is the instrument with which the doctor sounds our chests. He puts it to his ear, yet he calls it a stethoscope, which means "to see the breast". I am sure no one else dreams of seeing with his ears!

The bending of light is called refraction, a Latin word meaning "to break back". Perhaps you think that is rather an odd meaning, so you may think of refraction as meaning nothing more than to bend back. We touched on refraction in the last chapter, when we saw how Newton's

prism bent the ray of light *unequally* and so revealed the spectrum (p. 73). We must now go a little deeper into the subject, if we want to understand how light enables us to see, not only with optical instruments of various sorts, but with the most marvellous instrument of them all—the

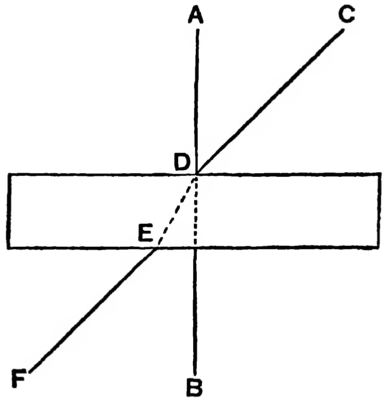


A beam of light entering a tank of milky water showing the bending of the light as it enters and leaves the liquid

living eye. We will start at the very beginning, by learning two easy rules. They are the rules of all vision, and it is by observation of them that scientists have been able to invent devices to improve our power of sight. The first rule is this: *When a ray of light passes in a slanting direction from one transparent substance or medium to another, the direction of the ray is changed both on entering and leaving.* And this is the other rule of refraction: *A ray of light passing from a rare into a dense medium is refracted towards the perpendicular—and from a dense into a rarer medium, away*

from the perpendicular. Of course " rare " here means less substantial; air is rarer or less substantial than water or glass.

You will agree that those are not hard rules to understand. Look carefully at the illustrations and I don't think you will have any difficulty in grasping them, especially if you remember what is meant by a ray of light—or of any other form of radiant energy. A ray is just a convenient division of the light that comes from an object. Each tiny point on the surface of an object is sending out light that spreads outwards in a " beam " which we can think of as a cone-shaped division of light. This beam is divisible into still smaller parts, called " pencils "; they are like the parts of a cone that is split lengthways into a great number of pieces with sides that are very nearly parallel. The pencils are again subdivided into still smaller parts, the rays. So we can think of a ray as the smallest possible straight line of light—millions and millions of them coming to our eyes from whatever we look at. In the illustrations here the artist has only drawn just a few rays to show how refraction works. Here is an illustration that I would like you to look at very carefully. It helps to explain a great deal of what I am going to tell you a little later about microscopes and telescopes. It is a neat little picture of a bit of glass seen end on.



AB is a ray of light which passes through the glass in a straight line because it falls perpendicularly. CD is an

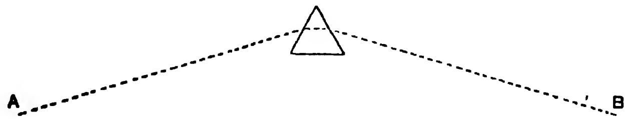
oblique or slanting ray, and it therefore becomes refracted as it enters the glass. Glass is denser than air, so the ray is refracted towards the perpendicular (the line AB); but on passing into the air again, it becomes refracted *away* from the perpendicular.

The interesting thing is this: when a ray passes through a glass with plane, parallel surfaces, like a window pane, or the bit of glass in the illustration, the angles it makes on entering and on leaving are the same. In other words, the ray CD and the ray EF are parallel. The ray CF has been twice refracted; but the only effect has been to shift the part that leaves the glass a little to one side of the straight line it would have followed had the glass not been there. So, although a window pane demonstrates the first law of refraction, it doesn't take us very far towards any of the marvellous optical instruments we want to examine.

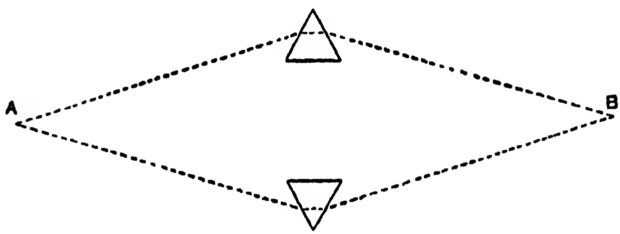
But suppose our bit of glass has irregular, instead of parallel, surfaces. What then? We have either a prism or a *lens*. In the last chapter we noticed that the remarkable thing about prisms is that they refract light *unequally*, the angles at which the rays are bent varying according to the wave-lengths of the energy-squirts. For the moment, however, I want you to forget this extraordinary property which gives us the spectrum, and only to remember that the angle at which a ray is refracted is a thoroughly useful, reliable servant. It is always the same for the same medium; we can always depend upon it, and alter it at will. In short, we can *bend* the ray so that it travels just where we want it. We alter the angle at which a ray *leaves* a prism by altering the angle at which it *enters* it. This is one of the occasions where those dull twins, Mathematics and Geometry, sit up and become exciting. It is they who really make it possible for us to have sextants and microscopes, spectacles and

cameras. What a pity we can't get on better with the twins!

Let us suppose we have a number of small glass prisms to play with, of different angles. Here is the one with the largest angles, shown with a ray of light passing through it; the effect is to divert the ray coming from the point A to the point B.

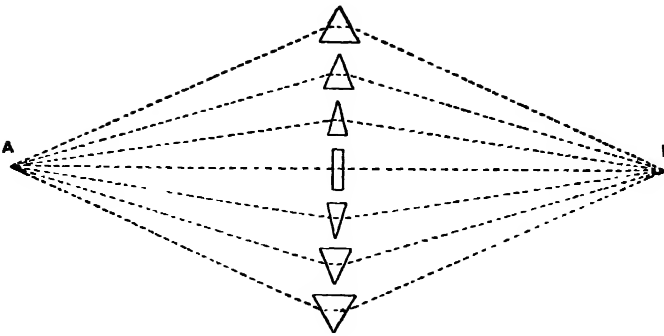


We can divert another ray from A to B by interposing a second prism, similar to the first, but with its angles reversed thus:



And now, suppose we take two prisms with smaller angles and interpose them between the first two. The smaller angles will divert the rays to a less extent, so we can direct still more of the light from A to B.

Indeed, we can go on interposing more and more prisms, each time using smaller angles (because as we get nearer the straight line joining A and B the rays require less bending or deviation) until we have collected a great number of rays coming from A and brought them together again at B. Finally, we put a piece of glass with parallel sides in the space between the two prisms with the smallest angles. If we used six prisms, this is what the result would be:



You are thinking; all this about prisms and angles is very boring. And we haven't got two each of three kinds of prisms. Perhaps not, but you carry a couple of *lenses* about with you, one on each side of your nose, and it is surely worth a little effort of concentration to find out how and why they work. These sketches of a series of prisms with different angles are put here because they show the way in which a lens acts by collecting the myriad light-rays reflected by objects and bringing them to a single point. Every ray carries with it an image of the point from which it proceeded, and our series of prisms enables us to unite a vast number of rays, and so to form at the point where they converge [1] a repetition of the image each conveys. The point at which the rays converge is called the principal focus.[2] It is rather important to remember that. It is also important to remember that the rays do not really stop at the focus, unless there happens to be something at that point to reflect or absorb them; they travel onwards in straight lines, so that the focus is also the point at which the rays *intersect* or cross one another.

[1] Converge—Latin, *con*, together, *vergere*, to turn.

[2] The distance of the principal focus from the centre of a lens is called the *focal length*.

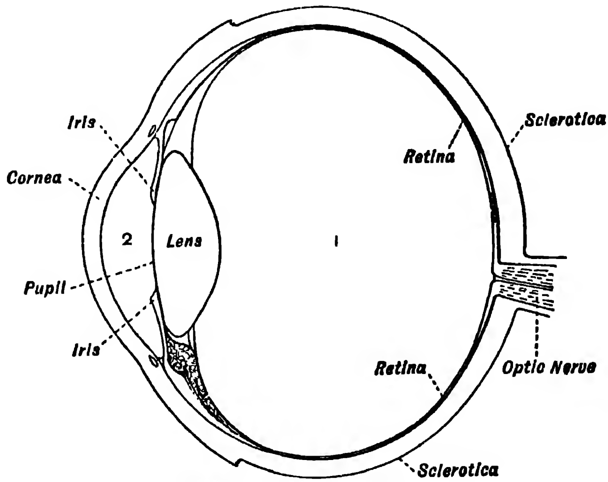
Well, you say, I can see that all right—but why talk about prisms when you really mean lenses? Only because the action of a lens is easier to understand if we use the simpler action of the prism. It is like explaining the high-pressure steam engine by pointing to a jumping kettle-lid. For a lens is in effect composed of a great number of prisms, of all sorts of angles, with their faces in many different planes. If you had enough prisms and enough skill you might be able to cement them together so that a section through their centres looked like a section of the convex lens shown in the illustration on p. 91.[1]

Let us have a look at our eyes before we go any farther, for it is not very easy to understand other optical instruments unless we know how those in our heads work. In the centre of the eye there is a black circle which we call the pupil; it is the opening through which the light enters. The amount of light that can come in is controlled by a muscular ring outside the pupil which expands and contracts to enlarge or diminish the opening. This is the iris; you can see it at work if you hold a candle or an electric torch in front of a friend's eyes. As you bring the light near to his eyes, the pupil grows smaller, as the iris reduces the opening. As you move the light farther away, the iris opens out to admit more light, and so more of the pupil is exposed. The amount of light entering any lens must be controlled in this way, or the image will be indistinct and blurred. That is why camera lenses are fitted with " stops ", or " iris diaphragms ".

Immediately behind the iris lies the marvellous *crystalline lens*. It is composed of great numbers of transparent, tape-

[1] There is one way in which illustrations of light rays refracted in lenses can easily mislead us. They can only show us typical rays in *one* plane—the plane represented by the surface of the paper. In reality, lenses collect and focus the rays in *all* the planes in which the light can enter them.

like fibres (obviously, all parts of the eye through which light passes are transparent) and its purpose is to focus the light rays on to the sensitive screen at the back of the eye. This screen is called the *retina*, from a Latin word meaning " net ", because it is composed of a fine network of nerves.



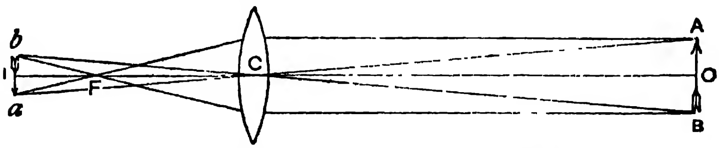
Section of the Human Eye

1. Vitreous Humour 2. Aqueous Humour. The transparent covering in front is called the Cornea. The covering at the back is the Sclerotica.

It consists of millions of sensitive cells, every one of which carries an infinitely small section of the image we see. When the lens focusses the light rays upon this network, the varying strengths of the " energy-squirts " we discussed in the last chapter excite or " stimulate " the cells in different degrees. The different stimulations pass along the optic nerve to that part of the brain whose business it is to sort them out and tell us what they mean. We know what the pictures mean—the significance of forms and colours, high-lights and shadows—because another part of the brain has stored up for us *memories* of the previous

pictures telegraphed by the optic nerve. The retina is stained black, and that is why the pupil always looks black. We see right through a person's eyes when we look into them; through the jelly-like outer covering of the lens (the *aqueous humour*) through the lens itself and through the *vitreous humour*, a jelly-like mass separating the lens from the black curtain on to which it focusses its picture.

I wonder if it has ever occurred to you that you look at things upside down and wrong way round? You can't help

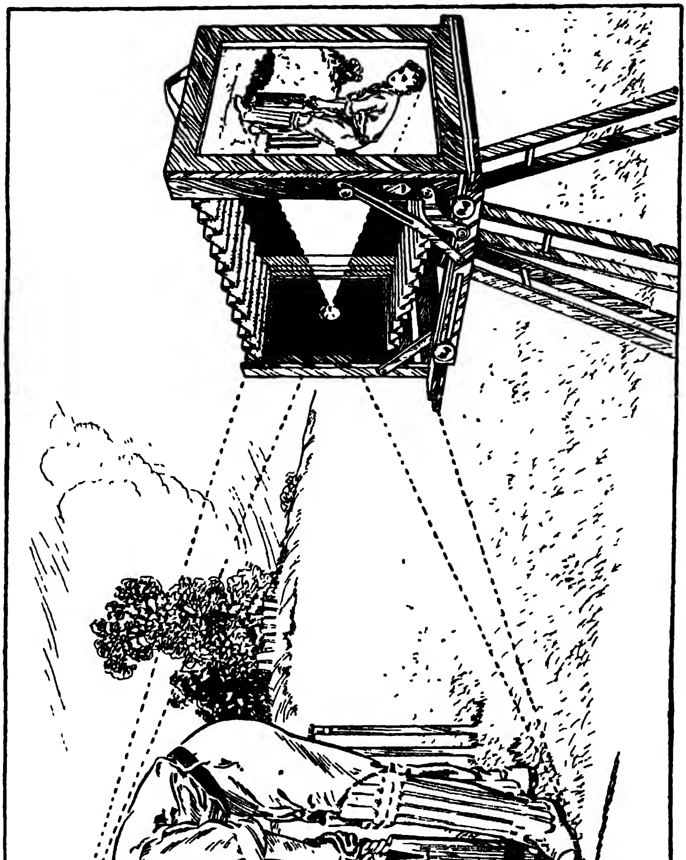


The Formation of an Image by a Convex Lens

AOB is the object, *aIb* the image—*a* being the image of A, *b* the image of B, and I the image of O. C, optical centre. F, a focus Two rays from A and B are shown before they enter and after they leave the lens.

it—we all do it. A convex lens bends the rays towards its centre, and it follows from this that many of the rays coming from an object must cross each other before they are brought to the focus.

The diagram above shows how the rays from the *lower* part of the object become focussed on the *upper* part of the retina, while the rays from the upper part are focussed on the lower part of the retina. Exactly the same thing happens on the photographic plate or film; the image is inverted, as you must have seen if you have ever looked at the image on the focussing screen of a camera. Every image made by a lens must be inverted in this way. We can put the picture the right way up by means of a mirror, or another lens. But our eyes have no such means; and it is left to our brains to reverse the pictures we really see. It is all done without our knowing anything about it, but I cannot tell you how it is done.

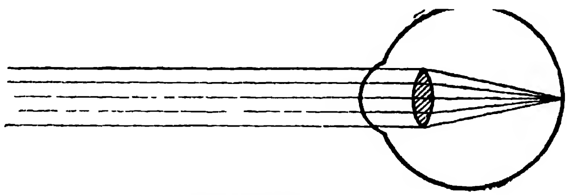


How the Image is formed in the Camera

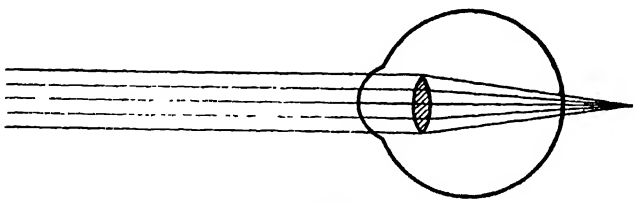
Those of us who have folding or "pocket" cameras know that it is necessary to move the lens away from the film in order to take good sharp pictures of near objects. We can use a screen of ground glass to bring the image into focus, or, more often, the front of the camera is made to traverse a scale, to show us the right focal length without any trouble. If it were not possible to move the lenses of our eyes in the same way, so as to alter the focal length, the retina could not receive clear images of things a few feet or yards away, and equally clear images of things hundreds of yards away. If the eye were focussed for distant objects, the rays from near objects would be bent to a focus before they reached the retina; and if the near objects were in focus, the rays from distant objects would not converge until they reached a point *behind* the retina. Well, we cannot push our eyes in and out, like snails, but we secure the power to focus by changing our lenses. We alter the refractive power by altering the *shape* of the lens. When we look at a near object, say 10 inches or a foot away, there are muscles which pull the front surface of the lens into a rounder shape. It becomes more convex, and at the same time the iris contracts, shutting out all but the central pencils of rays which fall upon the retina. You may feel the lenses of your eyes being changed in this way if you focus an object 8 or 9 inches away. You will find that you cannot see clearly without straining to do so.

Some of us have to wear spectacles. This is because the crystalline lenses do not focus correctly. They may not be quite the right distance from the retina to bend the rays so that they always converge on the retina. What happens then is shown in the diagrams. In the first one you see a normal eye focussing parallel rays coming from a distant object. The next diagram shows an eye that does not focus

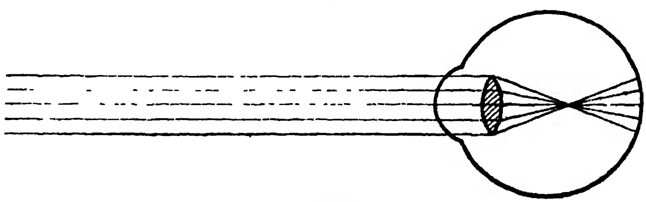
those rays. They converge at a point some distance behind the retina. People with eyes like these are said to be long-sighted, and their sight can be corrected by spectacles with slightly convex lenses, so as to bend the rays inwards before



Normal Vision



Long-sight



Short-sight

they enter the eyes. The bottom diagram shows short-sighted eyes. You see that the rays are brought to a point some distance in front of the retina. Short-sighted people cannot accommodate their sight to distant objects—things are blurred unless they are seen close to. The remedy here is the opposite of that used for long sight; the spectacles must have concave lenses, which are hollow and not bulging

—thinner in the centre than at the edges. Concave lenses turn the rays outwards, so that they have rather farther to travel before they can reach a focus on the retina. In other words, they are made to converge at a slightly more distant point.

And now that we know how it is we see in the ordinary way, we can better understand the method by which small things are made to look larger, and distant things nearer than they really are. We will have a new chapter for the wonders of optics.

CHAPTER VIII

Seeing beyond Sight

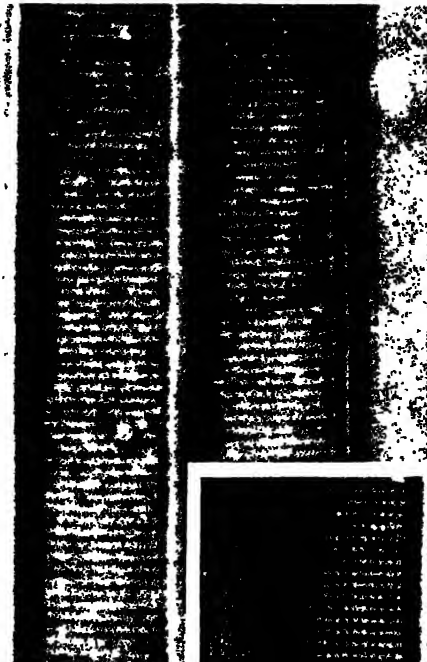
Have you ever written in a friend's " Confession Book "? It is rather a terrible kind of book, in which you are called upon to write answers to a list of questions. What is your favourite poem? Who is your favourite author? What do you consider the greatest virtue? asks the Confession Book, and I think you will agree that such questions take a good deal of thinking about.

When I was looking at a lady's Confession Book a little while ago, I was struck by the variety of the answers given to the question " What was the greatest invention?" People had put all sorts of things, but no two had agreed upon the same thing. One person had answered " printing ", another " weaving ". There were answers like " wireless " and " flying ", " the motor engine ", " the electric dynamo " and such things. It seemed to me odd that no one had thought of an invention that has certainly done more than

most others to forward the welfare of mankind. How came it that the writers in the Confession Book had overlooked the microscope?

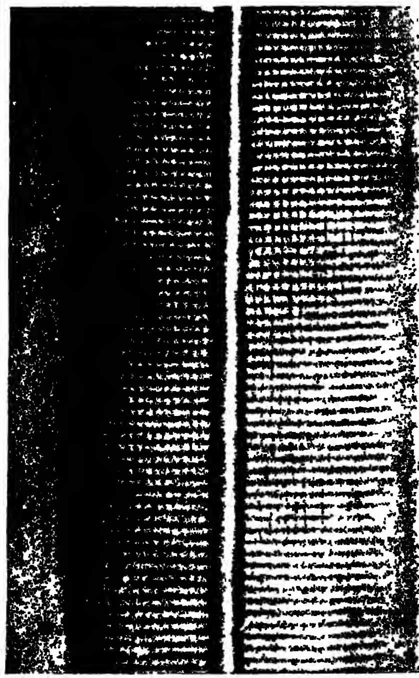
Very few of us use microscopes or have anything directly to do with them. I am quite sure that if every school had a compound microscope as a part of its equipment the microscope's claim to be regarded as an instrument of the foremost importance would be more generally admitted. The trouble is that so few people have more than the haziest ideas of what the microscope has done for them. Let us have a look at some of the ways in which this wonderful instrument has helped man to conquer the world around him.

It is hard to know where to begin, however, for whether we turn to the sciences which deal with living organisms, or to those which are concerned with the forms and properties of inorganic things, there is not one of them in which the use of the microscope does not play a very important part. Without it, we should still be without means of knowing anything at all about the growth and structure of the tiny cells of which all living things are composed. The microscope gave to doctors their power to conquer disease by revealing to them the life-history of microbes, not only of the diseases which afflict human beings and other animals, but also those, almost as direful in their consequences to humanity, which afflict plants. So, you see, our bodily well-being (and consequently our happiness) is really maintained by a marvellous little instrument by which the invisible is brought to light. And this same little instrument is always at the right hands of those whose job it is to see how the food we eat and the clothes we wear and the machines and implements we depend on may be made better, purer, more wholesome, more comfortable, nicer to look at and to touch,



Part of a diatom magnified 1000 times. Diatoms are microscopic organisms found in moist places.

Above is shown a part of the same diatom magnified 8500 times in visual light. At right the same part is shown magnified 8500 times in ultra-violet light. The increased detail obtained by the aid of the shorter rays can be seen. Photographed by B. K. Johnson, Imperial College of Science and Technology.



cheaper, safer, more reliable. I couldn't possibly tell you all the uses of the microscope, there are so many of them, but if you went down the High Street and bought a banana, a newspaper, a cake of soap, a tin of toffee, a box of matches, a new tie, a pot of paint, and a packet of screws, each and every one of your purchases would owe something to the microscope.

I dare say you would like to know who gave to science this extraordinarily useful invention—perhaps the most useful invention ever made. Unfortunately I cannot tell you; his name being lost to us for ever, nobody can say who he was. The Dutch claim that the first compound microscope was made by a Dutchman named Zacharias Jansen in 1590, but there is good reason to suppose that Jansen was not by any means the first in the field, and that microscopes had been made long before his time in Italy and England as well as in Holland. In any case, we may be quite sure that the simplest sort of microscope, consisting of a single lens, must have been in use for ages and ages before Jansen (or anybody else) used two lenses in a movable tube, for we know that the old Greeks and Romans had little globules of glass filled with water for use as magnifying-glasses and that more than 2000 years ago verses were written in such tiny lettering that they could not be read without the aid of the little globes of water.

But they were only toys, and so were all the instruments men devised for " seeing beyond sight " up to the middle of the seventeenth century. In 1656 there was printed a book called *Micrographia Illustrata*—a dull name for a book, I dare say you think. Very likely the people who read it in 1656 thought it an exceedingly dull book, and I don't suppose many took the trouble to read it. But I would like you to try to remember this book, *Micrographia*, by Robert

Hooke, because it showed, for the very first time, that the microscopes of those days, poor ineffectual instruments though they were in comparison with those of a century later, yet could reveal a new and fascinating world in miniature—a world of tiny forms and structures that no one had ever suspected to exist, since no one had ever seen it. So the revelations of *Micrographia* were really important.

I am sure you will be interested to know something of the life of the author of *Micrographia*, Robert Hooke, who was a very extraordinary person indeed, and one of the greatest geniuses the world of science has ever produced. He was born in the Isle of Wight in 1627 and lived until 1703, so you see he lived through the stirring times of the Civil War, and long enough to rejoice in the Restoration. He dwelt in London and knew the horrors of the Plague and the terror of the Great Fire, and the excitements of the great naval fights between Dutch and English. But he was too busy with science to take much interest in anything outside his own books and appliances and the beautiful mysterious ways along which they led him. It happens that we know a great deal about Robert Hooke through the writings of his friends, among whom were some of the most celebrated men of those days. One of them was Samuel Pepys, whose famous *Diary* you must read some day. Another was Robert Boyle, the great chemist about whom I told you in Chapter III.

You may remember that, as a boy, Robert Boyle suffered the terrible handicaps of physical deformity and ill-health. So also did Robert Hooke. His body was small and crooked and he did not go to school until he was thirteen, when he was sent to Westminster. But there was nothing the matter with his wits. He learnt the six books of Euclid in a week, it is said, and astounded his masters by the ease and rapidity

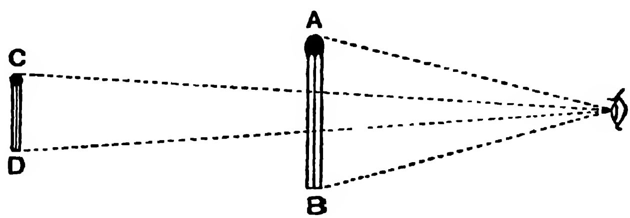
with which he absorbed knowledge. When he was fifteen he had devised " Thirty different ways of Flying " and thereafter, until his death, his extraordinary genius was establishing facts and testing theories throughout the whole realm of science, while also pouring out an unending stream of inventions. Microscopes, telescopes, sextants, clocks, watches,[1] air-pumps, thermometers, musical instruments, coach-springs, felt-making, architecture—these were some of his practical activities. He made important discoveries in the nature of heat, sound, light, and gravitation. He forecast the coming of the steam-engine and even of the telephone and aeroplane. And we must try to remember that it was Robert Hooke's *Micrographia* that raised the microscope to its immensely important place among scientific instruments.

Now, of course, Dr. Hooke understood the refraction of light. I dare say men first discovered the magnifying power of a convex lens in some accidental way; perhaps someone put a glass bead very close to his eye and found that a tiny speck beneath the bead became astonishingly large. But we may be quite sure that it was a very long time before men came to realize that the reason why the speck became large was simply that the glass bead had brought it *closer to the eye*. In those four words you have the explanation of the magnifying power of a convex lens. The largeness of anything depends entirely on how closely you look at it. A match-stick seen at a distance of one foot is a much larger object than a match-stick seen at a distance of ten feet; and a thing seen at a distance of ten feet looks much larger than it looks at twenty feet.

The explanation is that the *apparent* size of anything

[1] The balance wheel and escapement by which clocks and watches can keep good time were first satisfactorily applied by Robert Hooke.

depends on the angle at which the rays issuing from it converge upon the eye, that is, the angle formed by two lines drawn from the extremities of the object to the centre of the eye. In the sketch here, the lines drawn from the eye to the match-stick AB form an angle nearly twice as large as the angle formed by the lines from the match-stick CD, at twice the distance. The consequence is that the match-stick AB looks nearly twice as large as the match-



stick CD. In like manner, the size of everything we see depends on this "angle of vision". It follows that if you looked at a tiny object, the leg of a gnat, say, and held it very close to your eye, the object would be very much magnified. The trouble is that you either cannot see it at all, or else it is so blurred and indistinct that you cannot say what it is.[1]

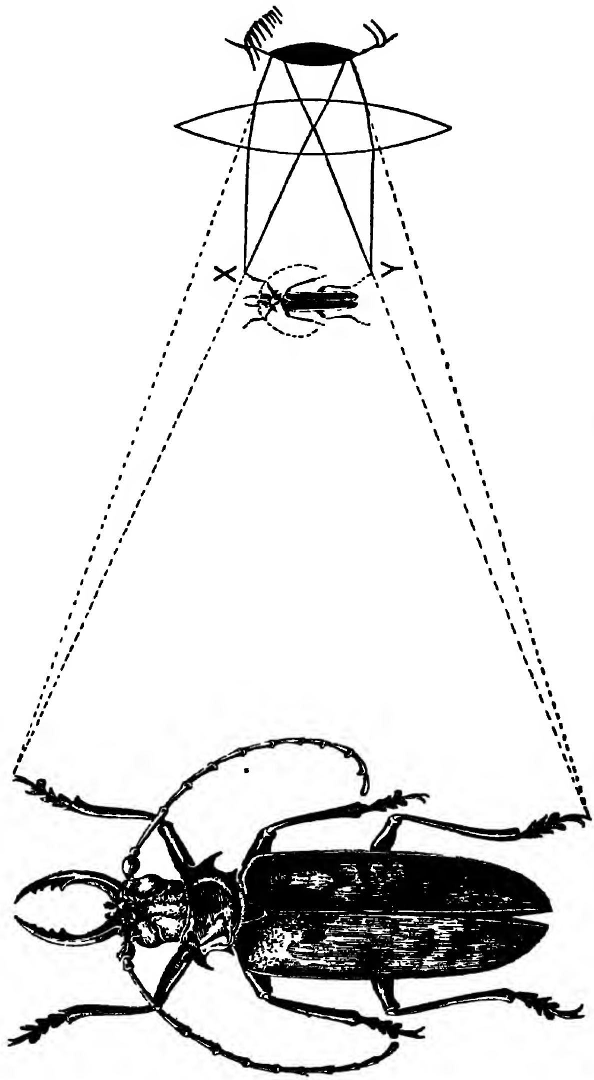
I think you will be able to understand why this is, if you recall what was said in the last chapter about the lens of the eye. The purpose of the lens of the eye is to refract the rays of light so that they are bent to a focus on the retina. But if an object is very close to the eye, then the pencils

[1] You can see it clearly, however, much magnified (about ten times) if you care to go to the trouble to do this blacken a card, and glue to the back of it a piece of stiff paper on to which you can attach the gnat's leg so that the latter is about an inch from the card. Make a tiny hole in the card with a fine sharp needle, exactly opposite the object to be viewed Now hold the card close to your eye and look through the needle-hole. You will be surprised at what you see. Your lensless miscroscope is explained by the fact that the tiny hole limits the divergence of the rays from the object, so that the lens of the eye can make some of them converge on the retina.

of rays from its extremities form so large an angle that the lens cannot gather them to a focus. We can see things clearly up to a distance of about a foot from our eyes; anything nearer than that is out of focus. Fortunately, however, it is an easy matter to bring a suitable convex lens between the object and the eye, so that the pencils of rays are first of all bent to such an angle that the lens of the eye can collect them and bend them again to a focus on the retina. Therein lies the secret of the magnifying-glass.

But it is not easy to understand all this without a diagram, so you must look at the sketch on p. 102. It shows a beetle held close to your eye, and a lens between. Now, you see how the rays of light from the extremities of the beetle form cones with their points at X and Y. (You must not forget that we can only show in a drawing *typical* rays in a single plane.) If the lens were not there, these rays would miss your eye altogether, they are so divergent. But the lens bends them into nearly parallel rays which *can* reach the eye. The result is that you see, not the tiny beetle at XY, but an *image* of the beetle. This image is at a convenient distance to look at, and moreover, magnified very considerably.

That is the simplest form of microscope, and I hope you see how it acts. Any magnifying-glass is a simple microscope, so-called to distinguish it from the infinitely more powerful compound microscope. Before we examine the latter, however, I must explain that if you went into an optician's shop and asked for a simple microscope, the shopman would produce a very elaborate-looking instrument on a stand. It would be capable of high magnification—high enough to enable you to examine and dissect animal and plant tissues. The point is that although the simple micro-

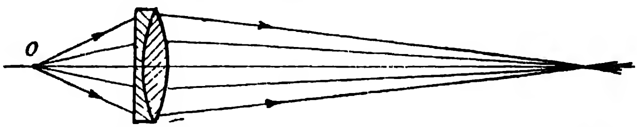


The Simplest Form of Microscope

scope only magnifies the object *once*, i.e. the observer sees an image from which the rays are brought to a focus directly to the eye, it consists not of a single lens, but of at least two, and generally of three. And the reason is to be found in the nature of every lens. To understand it, we must go back to the last chapter.

You probably thought it was rather a dull bit in the last chapter, where I said that we could regard lenses as if they were composed of a number of prisms, but I put it in for the very good reason that it helps to explain much that is otherwise hard to explain. For if the surface of a lens really consisted of the plane surfaces of a vast number of prisms, why then (if anyone had the skill to arrange all the faces at exactly the correct angles) it would be possible to bend all the light rays collected by the lens in such different degrees that they all came to a focus at the same point. But that is impossible. A lens is part of a sphere, that being the only shape to which it can be ground with the necessary accuracy. Yet this spherical shape has two very great drawbacks due to the fact that the varying thickness of the glass refracts the rays unequally. Those which pass through the thin glass at the circumference are bent *more* than the rays passing through the bulging centre part, so that they are brought to a focus at a shorter distance behind it than the rays nearer the centre. This is called *spherical aberration* (aberration only means " wandering "). The second drawback is another form of aberration called *chromatic aberration*, or as we may call it, " colour wandering ". You can see it whenever you look at a page of print through one of those large magnifying-glasses called reading glasses; the letters are all seen to have coloured edges. Remember how we analysed light into its component colours in Chapter VII; we saw that this was possible

because the different frequencies of the light-waves that give us our colour sensations have different angles of refraction. The long red wave is much less bent than the violet wave, which is only half the length. The result is that the ray of light, instead of carrying a single image, becomes split into as many coloured images as there are colours in the spectrum. The red wave brings us a red image, the orange wave an orange image, and so forth. So the effect



A plano-convex doublet-achromatic lens placed with its plane side nearest the object The rays diverging from a special object point O will be brought together at O′. That is, there is freedom from spherical aberration.

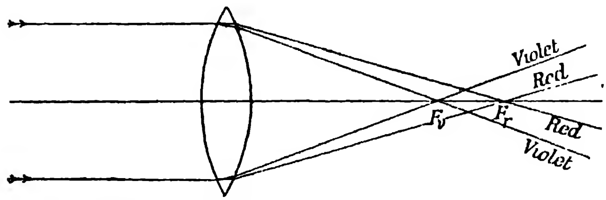
of any lens is to separate out the wave-lengths, bringing them to different foci.

The result of these two forms of aberration is to make the magnified image blurred and indistinct, which is, of course, a very grave defect. A microscope must give a clear image, and good definition or " resolution " is just as important as magnification. The disadvantage of spherical aberration was first overcome by a celebrated English chemist whose name is now forgotten except by scientists. This was Dr. Hyde Wollaston [1] who invented the form of lens called a " doublet ", because it really consists of two distinct lenses, of the shape called plano-convex. A plano-convex lens bulges outwards on only one face, the other face being ground perfectly flat. The two lenses of the doublet are placed with their plane surfaces towards the object to be examined. They are of different focal lengths, so the distortion of the first lens is corrected by the other. A still clearer image

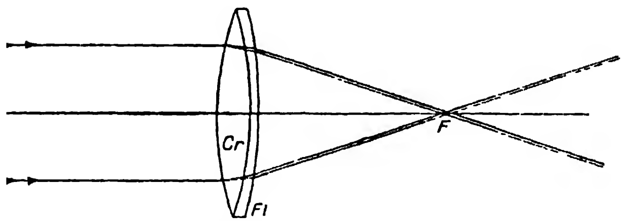
[1] Born 1766, died 1828 Dr Wollaston made many important discoveries in chemistry and optics. He was the first to reveal the existence of ultra-violet rays.

results if a third plano-convex lens is used to correct the other two.

Dr. Wollaston's doublet made the microscope a very valuable instrument of science.[1] But the "colour fringes" due to chromatic aberration were much more difficult to cure. Year after year great brains were concentrated on the problem



If a lens is not achromatic the various colours have different foci



An achromatic lens formed by a combination of a convergent lens of crown glass (cr) and a divergent lens of flint glass (F) brings the various colour rays to the same focus (F)

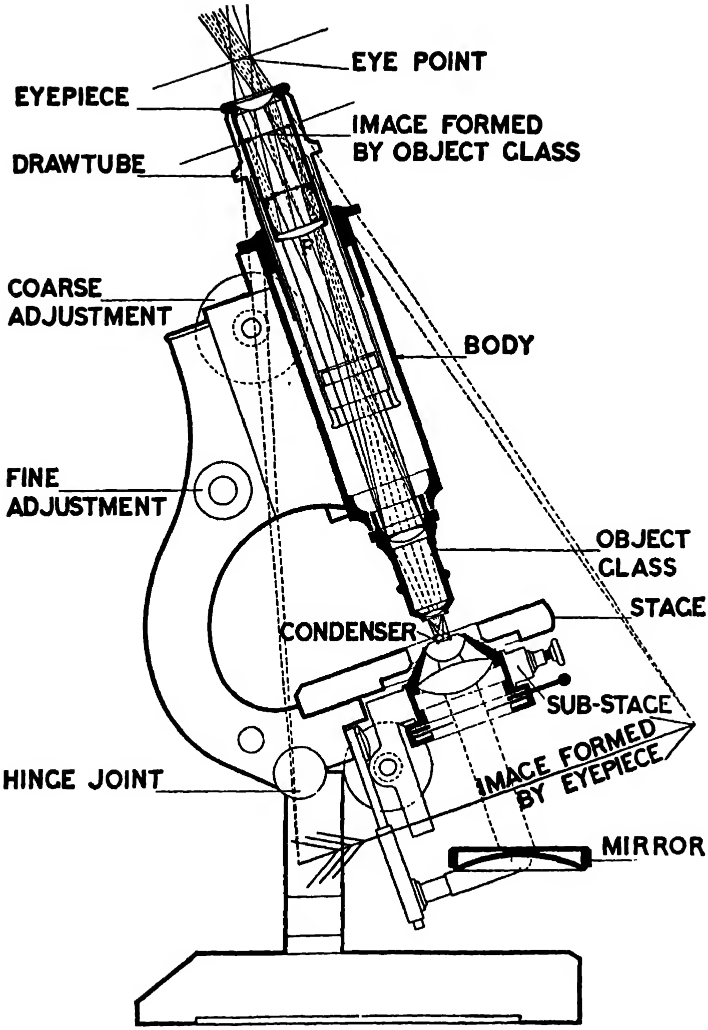
and it was eventually solved in a very ingenious manner. The lens was made of two kinds of glass of opposite form, having different refractive powers. One kind of glass, called crown glass, was ground into a convex lens, with bulging sides; the other kind of glass (flint glass) was ground to the shape called plano-concave, flat on one side and saucer-shaped on the other, the saucer being of exactly the same shape as that of the convex lens. The two lenses are carefully joined. When a ray enters the convex lens of crown glass

[1] Since his time many different combinations of lenses have been adopted to correct spherical aberration.

the various colours are bent to different foci, as shown in the upper diagram. The convex lens of crown glass brings the rays together again, bending them unequally outwards, so that most of them meet at a common focus, thereby producing a reasonably clear image.

The modern microscope is a truly marvellous instrument, of an ingenuity of design and of an exquisite workmanship surpassing almost everything else. Indeed, its value to science depends on the exactitude with which it is made. For the slightest error in the curvature of the lenses or in the precision with which all the parts are fitted together will render the high-power compound microscope completely useless. We do not, as a rule, give much thought to the science of optics, nor to the work of those whose lives are spent in grinding lenses and fitting them into the hundreds of appliances that contribute so greatly to our comfort and safety. So we ought at least to take the trouble to learn something of the mysteries of so useful a science.

I have taken you into the difficulties of this splendid science of optics, and have touched at some length on the means by which the difficulties have been overcome, so that we may approach the mysteries of the modern microscope without feeling that they are too deep for ordinary people to understand. And we must now go back to the principle of the simple microscope before we can grasp that of the far more powerful compound microscope. There is a very important difference between the two, for in the simple microscope we look at an object directly; what we see is, in effect, the *image* of an object that is very close to the eye, projected to the distance at which we can see it clearly. But in the compound microscope we do not look at the object directly. There are two lenses (or sets of lenses) which perform different functions. The function of the



A sectional drawing of a microscope showing the rays passing through the instrument, F is the field-glass. Reproduced by courtesy of Messrs. R. & J. Beck, Ltd.

first lens (or set of lenses) is to form an image or picture of the object to be examined; the function of the second lens (or set of lenses) is to enable us to see this image or picture by bringing it to a focus on the eye.

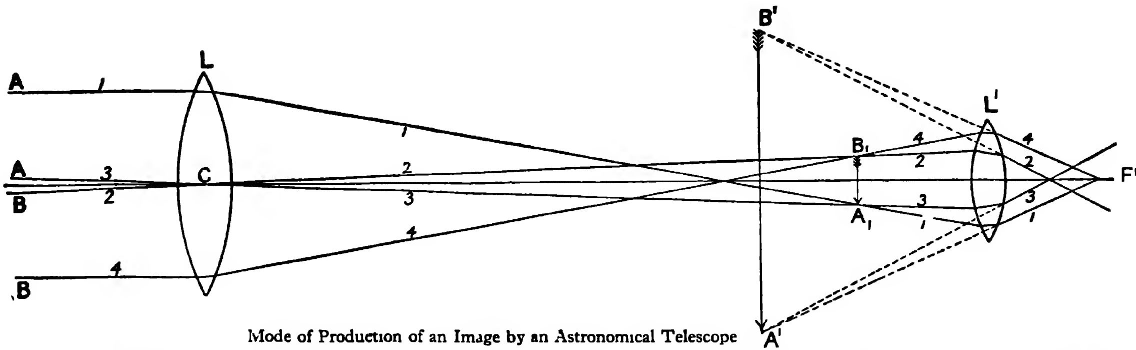
The sectional drawing of a microscope will help to make this clear. It shows how the much-magnified image of an object on the stage of the microscope comes to be presented to the eye. You will notice that there are two systems of lenses, arranged in tubes sliding one within the other in such a way that the relative distances of the two systems can be very finely adjusted. The object to be examined is placed as close as possible to the first set of lenses, called the objective. Owing to the nearness of the first lens to the object, the rays enter this lens at very wide angles, with consequent distortion or aberration. The purpose of the other lens in the object-glass system is to correct this, as explained on page 104.

The upper system of lenses is the eye-piece. It consists of two plano-convex lenses, of which the one farthest from the eye (marked F on the drawing) is called the field-glass because it increases the range or " field " of vision. The field-glass is placed so that it intercepts the rays bent by the object-glass before they come to a focus, at the point shown by the arrow a little distance above the field-glass. At that point, therefore, the rays from the object-glass form a much magnified inverted image of the object, but the image could not be seen unless something was placed there to intercept it. But the field-glass again bends the rays so that an image is formed by the object-glass at a point a little below the eye-piece, as shown by the upper arrow. It is this image, produced by the objective, which is viewed by the eye-glass as if it was the real object itself. The eye-piece is of such a shape that it again magnifies the magnified image produced

by the objective, so that the magnifying power of a compound microscope depends on the product of the separate magnifying powers of objective and eye-piece.

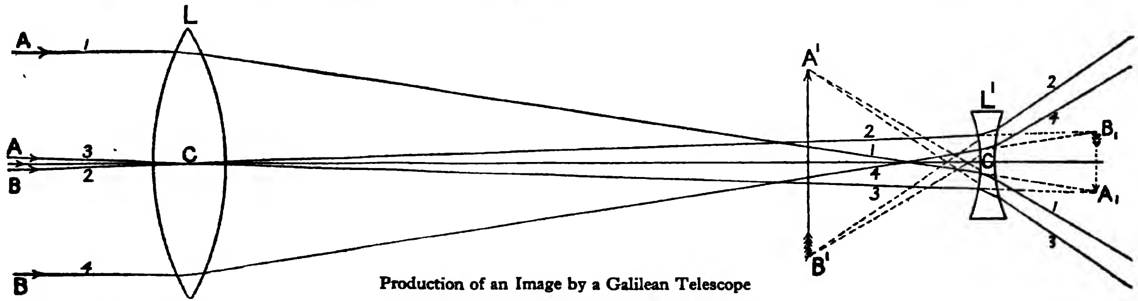
One of the greatest difficulties of high-power magnification is due to the very small amount of light that can be reflected from the object. The lenses of greatest magnification are the smallest, and they admit such narrow pencils of light that the object is difficult to see. This can be partly overcome by concentrating an intense light on the object. Beneath the "stage" on which the object is clamped there is an arrangement of lenses having the effect of a bull's-eye, called a "condenser" because it collects and stores up the light reflected from a mirror. It makes it "more dense", in fact, and concentrates it upon the object.

When we were talking about chromatic aberration a little while ago I told you how the different colour-frequencies were first of all spread apart and then made to converge at a common focus by using the lens made of two kinds of glass of opposite shapes. The purpose of such an achromatic lens is to give a clear, well-defined image. But it sets a limit to the size to which an object may be magnified. The "resolution" of minute objects—the power to separate them from each other so that they may be clearly seen—ultimately depends on the length of the wave of light which strikes them and rebounds from them. A wave of red light is about 1/33,000 of an inch long, and so red light could not resolve or separate objects only 1/40,000 of an inch apart. The mean wave-length of ordinary light is 1/45,000 of an inch, and so anything smaller than that can never be clearly seen however great the magnifying power of the lens. The only reason why we do not magnify microbes up to the size of table-tops is that we should not be able to tell whether we were looking at a microbe or a table-top. But if we use



Mode of Production of an Image by an Astronomical Telescope

AABB are rays coming from a star. The lens L (the object-glass) forms an inverted image B_1A_1 which is magnified by the eye-piece lens L^1 to the size of B^1A^1. The eye is placed at F^1 to see the image. The path of the rays can be traced by the numerals 1, 2, 3 and 4.



Production of an Image by a Galilean Telescope

The rays on their way to form the image A_1B_1 are intercepted by the concave eye-piece L^1 and are changed from a converging to a diverging beam. Hence the image is seen at A^1B^1. It will be seen that the use of a concave eye-piece makes the length of the instrument less than if a convex eye-piece is used.

the shorter wave-lengths we may hope to see smaller things than the long wave-lengths can show us, since the shorter the wave the more detail it can carry to the eye.

The difficulty was that until about fifty years ago there was no known glass of just the right density to refract the very short rays of the spectrum. It was a great German mathematician, Professor Abbe, who finally solved the difficulty by inventing a new glass exactly suitable for bending the violet rays. Lenses made of this glass were able to give clear images of things as close together as 1/60,000 of an inch. The next step was to make use of still another kind of glass, able to refract the ultra-violet rays. Now, we cannot see these rays, for they are too short to have any effect on our eyes; consequently no image would be visible in a microscope in which they were employed and ordinary light shut out. The photographic plate is sensitive to them, however, and thus photographs can be taken of things that are so minute that they are altogether beyond our power to see, being far beyond the range of any microscope using ordinary light.

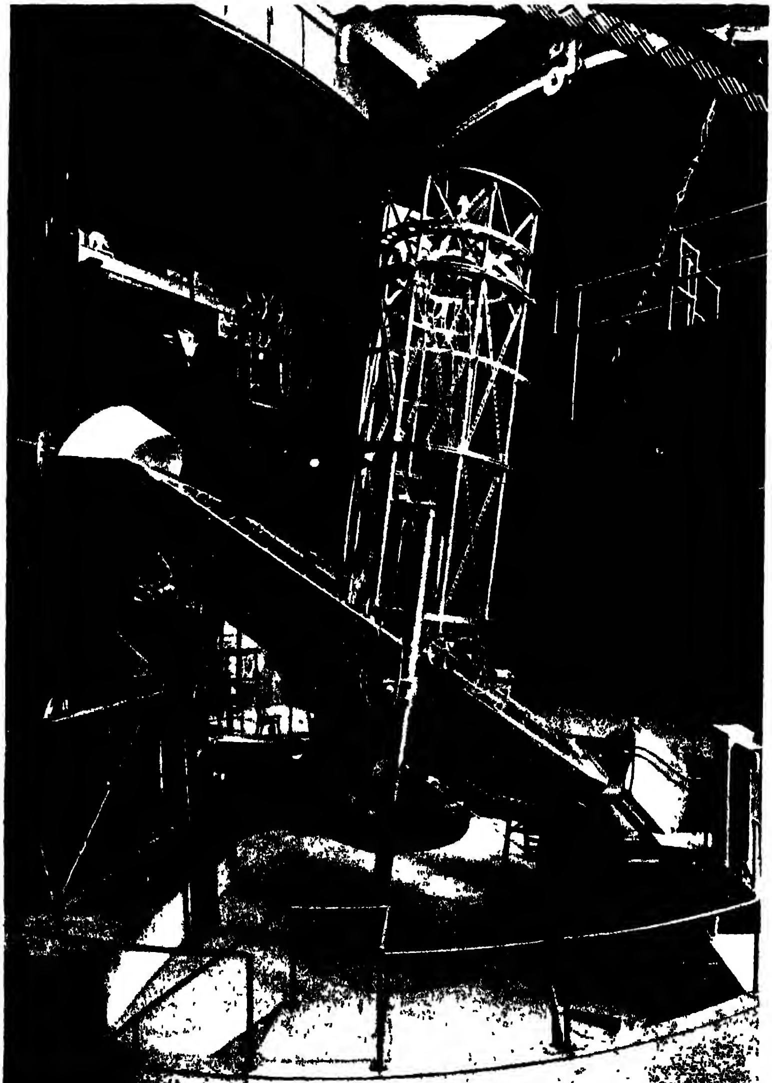
We may close this chapter with a hurried glance at the wonderful kind of microscope which most of us probably use, or have used, more than any other—the telescope. The principle of the telescope is really very simple, and if one understands how the microscope acts there should not be any difficulty in applying it to objects at a great distance. We know that to make an object bigger we have only to bring it nearer to the eye. The purpose of a telescope is twofold: it must first collect the rays of light coming from a distant object and then bring them to a focus so that they form an image at a point in space as close as possible to the eye. The second purpose is to enable the eye to look at the image thus brought close up to it, and we have the

instrument we need for this purpose in the simple microscope or magnifying-glass.

Either a mirror or a lens can be used to collect the rays of light. Telescopes with mirrors are *reflecting* telescopes; those in which the light is received by a lens are *refracting* telescopes. The simplest kind has but two lenses, an object-glass of convex form to collect and bend the rays to a convenient focus, forming an inverted image that is viewed through another convex lens acting as a simple microscope. In looking at a star it does not matter much that we see it upside down, but in looking at a ship or a distant view the upside-down picture is confusing. Therefore two other convex lenses are introduced between the image projected by the object-glass and the eye-piece. These give a more magnified picture, the right way up.

Another very simple kind of telescope is the one called an opera-glass when it is used in a theatre, and a field-glass when it is used out of doors. The great sixteenth-century scientist Galileo, having heard about a telescope invented by a Dutchman, made such an instrument for himself. The first night he used it (7th January, 1610) he discovered some of Jupiter's moons. Is it not remarkable that after more than 300 years we still use the Galilean telescope—or rather, a pair of them, one for each eye—when we go to the theatre or to an athletic sports meeting? It is really a refracting telescope in which a convex object-lens bends the distant rays to form an image that is intercepted by a concave eye-lens. A concave lens spreads the rays *outwards*. The effect is that the eye sees them as an erect image at a much shorter distance.

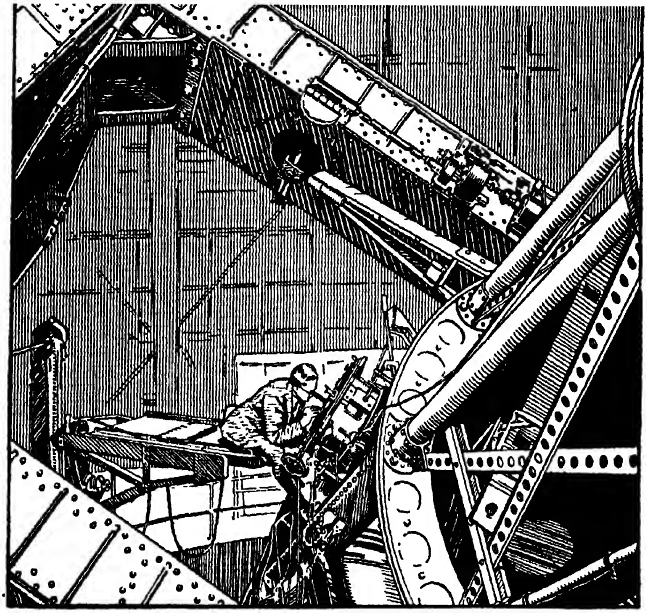
The great telescopes used in astronomical observatories chiefly employ the reflecting principle. In these huge instruments (which are of far greater importance to our wel-



MOUNT WILSON OBSERVATORY

A view of the interior of the dome showing the 100-inch reflector. Cassegrain observing platform, &c , as seen from the west. See also illustration on opposite page

fare than people imagine) a great concave mirror is used to catch the rays proceeding from a distant object, such as a star that is invisible to the unaided eye. A secondary mirror is used to intercept and turn aside the rays reflected



An Observer at the Eye-piece of the great Mount Wilson Telescope

by the first mirror so that they form an image at some point where they can be comfortably examined by a magnifying eye-piece. The reflectors of such telescopes are gigantic. A new reflector for Mount Wilson Observatory in California will be 200 inches in diameter. The difficulties of casting, annealing, and grinding a piece of glass of such a size, weighing perhaps 25 tons, are scarcely believable.

The mirror must be ground to a curved surface perfectly accurate to 1/500,000 of an inch.

But as to that, the great astronomical telescopes are marvels of ingenuity and exquisite device. In no branch of science has a higher perfection been reached; but to understand the inventive genius that has made this perfection attainable, to know the real beauty of the wonderful mechanism by which, for example, the camera at the end of a tube on our turning planet is kept focussed on an invisible star with absolute precision, you must know something not only of astronomy, but of many another science by which the forces of Nature are chained to man's service.

CHAPTER IX

Amateurs who made Photography

In these days when we all take photographs (mostly, I fear, very bad ones), it might reasonably be supposed that we were all well up in the art and science of "drawing by light".[1] But so far from this being the case, most of us know nothing whatever about photography. All we know —most of us, that is—is how and when to press the button and to change the film. The rest of the work is done for us. The shopman with whom we leave our exposed films sends them on to a works that is specially equipped for developing and printing amateurs' "snaps". It saves us a great deal of trouble to have the work done for us in this way, but it also deprives us of the interest and enjoyment of making our own pictures from beginning to end, instead of merely "taking" them. I think you will agree that it

[1] Photography means "light-writing".

is rather a lazy sort of way of recording the events that interest us, and that there is small reason to be proud of a photograph when we have brought but a small effort to make it. However, the system is found to be a convenient one (which is why we all support it), and it probably saves us our pocket-money and the disappointment of failure as well. So we must not be too hard on it.

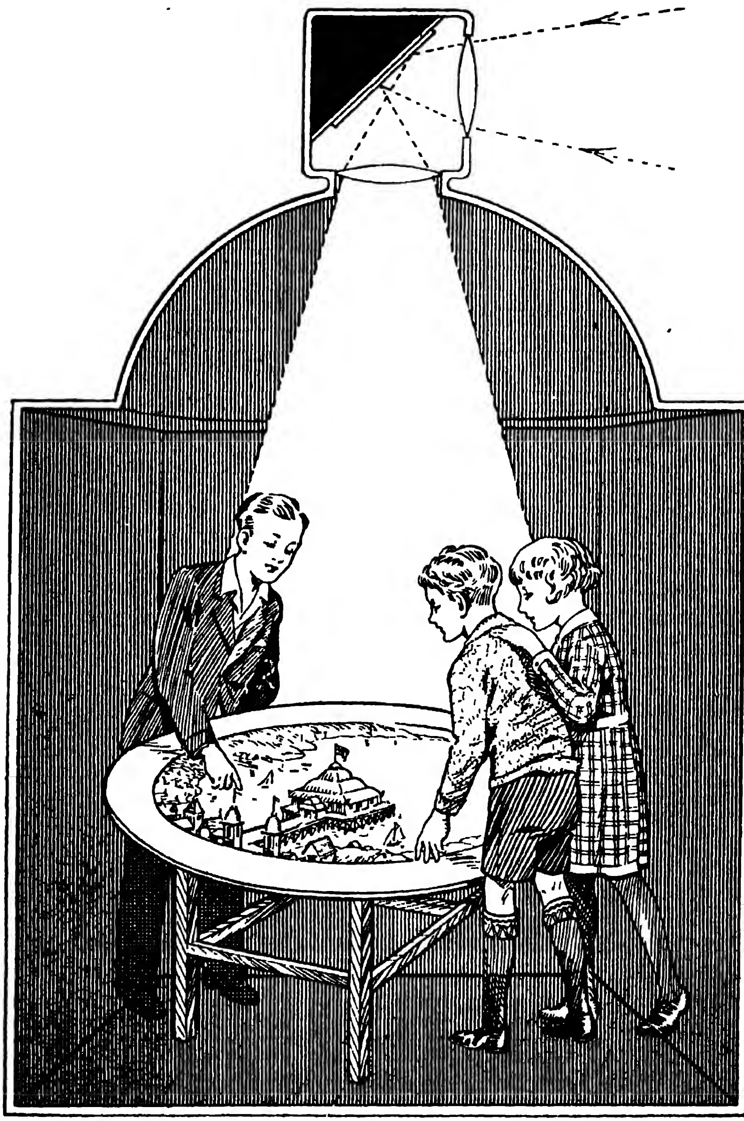
However, when I was a boy there was no handy photographic chemist just round the corner to whom I could take my exposures with a "please let me have these by to-morrow morning", or if there was I never knew him. I took my photographs on glass plates, because I believed that the lightness and convenience of celluloid films were outweighed by their disadvantages. I did my own developing as a matter of course; my own printing, enlarging, lantern-slide making. So did all amateur photographers in those days, which were not nearly so long ago as they sound! And in order to carry out these processes with a reasonable prospect of success it was necessary to know what changes were taking place in our chemicals under the action of light.

The science of photography depends on the power of the lens to bend light to a focus in a dark box, and on the power of light to change the nature of certain chemicals. The dark box was in existence hundreds of years before anything was understood about the chemical action of light. It was called *camera obscura* (Latin, "dark chamber"), and it was invented, or at least described, by an Italian named della Porta as long ago as 1569. You may have seen the camera obscura at the seaside, where it still survives as a side-show on piers and in "amusement parks". You enter a dark chamber and there, on a table in front of you, is a picture in miniature; tiny people on the shore, the

boats and the bathers, the traffic moving on the parade, all in their natural colours and with the fairy-like delicacy that makes a picture in the view-finder of a camera so fascinating. Indeed the view-finder and the camera obscura are one and the same. A lens focusses the picture on to a mirror at an angle of 45°, which in turn reflects the picture on to a screen. In della Porta's time the camera obscura had no lens; that was a much later improvement. The light was admitted through a hole in a shutter, and the hole had to be very small, or the pencils of light spread out so much that the picture was too indistinct to see. But the tiny hole admitted so little light that even at its best the picture was dark and difficult to see. The lens was a great improvement. It could be made to fit a much bigger hole, admitting enough light to give a bright, well-illuminated picture, and a sharp one. We know that the function of a convex lens is to focus the light rays to a point.

Although the lens is always the most important part of any camera, and the most expensive part, it is not an essential part. You can take good clear photographs without a lens. Let the light reach your sensitive plate or film through a tiny hole in the front of a light-tight box, as in the manner of the early camera obscuras. If the camera is quite steady, and the subject of the picture quite still, the tiny trickle of light through the hole will record the image it carries—in time. It would take twenty minutes, I suppose, on a bright day out of doors—which is longer than we care to wait now that our half-guinea cameras do the job better in the click of a shutter. Such pin-hole cameras were very popular with boys at one time. The toy-shops sold them for about sixpence, but we mostly made them for ourselves.

Photography is a modern science. It was born less than a hundred years ago, and its history is extraordinarily



A view of the inside of a Camera Obscura showing how the image of the outside scenery is formed on the table

interesting and romantic. In one respect the story of photography differs from nearly every other science. It was set on its feet by amateurs, men with little or no scientific knowledge, and some of the most important discoveries in the early stages of photography were not the outcome of serious research but just very lucky accidents, though perhaps that is not altogether true of the man who took the first sun-pictures.[1] This was Joseph Nicéphore Niepce (there's a name to stick in your memory!), a dreamy young man of the late eighteenth century who could not make up his mind what he wanted to be. He went soldiering for a time, and then settled down to become an official of the French Government. I think his job must have been an easy one, for he found time to invent all sorts of mechanical contrivances, none of them of any practical importance. And then, in 1796, somebody else invented something that turned Niepce's mind to experiments that led directly to the huge photographic industry of our own days. You would not guess what this invention was if you tried a hundred times. It was lithography; the art of printing from stone blocks.

Lithography is about as remote from photography as anything can be, except that both words are compounds of the Greek *grapheo,* I write—" stone-writing " and " light-writing ". The principle of lithography is very simple. If you draw on certain kinds of limestone an upside-down picture, or write on it in upside-down writing, using grease instead of ink; and if then you wet the stone and pass over it an inky roller, the ink will stick to the greasy drawing

[1] A Swedish chemist, Carl Wilhelm Scheele (1742–1775), found that the effect of sunlight upon chloride of silver is to decompose it, and about the same time Dr. Lewis of London made experiments with the darkening of silver salts by sunlight. Some few years later Josiah Wedgwood, the famous potter, made similar experiments with a view to discovering a method by which light would print designs on glass. But nothing came of them.

or writing but not to the parts of the stone where the water has been. So you may take off on paper an imprint of whatever you put on the stone in grease. In short, the inventor of lithography (his name was Senefelder) showed a new way of printing, one that was particularly useful for book illustrations.

It seemed to Niepce that the skill required in drawing the design on the stone was the great drawback to the process. And presently there came to him a fantastic thought—what if the sun could be made to draw the picture on the stone. His imagination dwelt on the fascinating little picture in the camera obscura. Suppose the light coming through the lens could be made to act on some chemical substance that should catch and hold that delightful picture?

On that fantastic notion he went to work. He tried silver salts on a metal plate placed in the camera obscura, having learnt that where the sunlight reached these salts it would blacken them. So it did, but he knew no means of fixing the image. Presently he heard of a different substance altogether, a kind of asphalt called bitumen of Judea, that in the ordinary way is soluble in oil of lavender—the pleasant smelly stuff, expressed from lavender, that is often shamelessly offered as a midge scare. Now oil of lavender will not dissolve bitumen of Judea if the latter has been exposed to light.

Niepce coated a metal plate with the bitumen, exposed it for a very long time in the camera obscura, at the spot where the lens cast its image, and then " developed " his plate in oil of lavender. Of course there was nothing to be seen; but the oil of lavender dissolved the bitumen in the dark parts of the picture—the parts where the light had not been—while it left a coating of insoluble bitumen wherever the sunlight had affected it. There was nothing

to be seen; but the ingenious Niepce next treated his plate in a bath of acid. You will not need to be told what the result was. The acid ate into the metal wherever it was not protected by the bitumen rendered insoluble by the light. Thus he made the first " light-picture " (though I do not suppose the picture was much to look at), and thus, too, he made the first photographic block for the printing press. After this he discarded the camera obscura, and confined himself to making transparencies, pictures drawn on paper oiled to make it transparent, that the sun printed for him on his bitumen-coated plates.

Niepce was not a scientist. He was a very gentle, unbusinesslike, unworldly " potterer " about the portals of the treasure-house of science. His friends probably regarded his experiments as the recreation of a harmless lunatic. But it chanced that there was at that time living in Paris another harmless lunatic, who, like Niepce, had a great desire to fix the exquisite image of the camera obscura. This man's wife thought him mad indeed, and could not understand why he would not stick to his job, that of a scene-painter. He was Louis Jacques Daguerre. He was a good scene-painter. He liked to be exact in his details, and he used to make careful studies from the image in a camera obscura, to guide him in making his drawings.

What a pity that the lovely little camera obscura picture couldn't be made to stay—for always! Daguerre was even less of a scientist than Niepce, though he was much the same kind of " potterer ", and wasted his time over futile experiments with chemicals, trying to find some substance on which light would fix its pictures. One day he heard of his fellow-countryman who was struggling with the same ambition. Presently, Daguerre and Niepce joined forces, accident again showing the way. The bitumen and

oil of lavender were laid aside, for Daguerre's experiments were made with silver compounds that promised better results. Niepce died before anything came of them, "without glory, forgotten by his fellow-citizens, with the bitter thought present in his dying hours of having consumed twenty years of his career, dissipated his patrimony, and compromised the future of his family in the pursuit of an idea". So said his biographer.

Louis Jacques Daguerre

The scene-painter plodded on alone. He had got so far as to expose in the camera silver plates that had been treated with iodine vapour. The iodide of silver became decomposed where the light reached it, and after a very long exposure in the camera, from four to six hours in strong sunlight, there was produced on the plate a very faint and unsatisfactory image. At that stage Daguerre might have stuck for ever had it not been for an extraordinarily lucky accident that pointed out the next step.

The would-be photographer exposed a sensitive plate for another attempt. Then the sun went in. In disgust, Daguerre removed the plate from the camera and put it away in the dark cupboard where he stored his chemicals, intending to resensitize it on another occasion. And when next he went to the cupboard he was not sure whether he was awake or dreaming or whether he had stumbled on a tame magician. Confronting him was the discarded, under-exposed plate, and on its surface the fair picture on which his heart and mind were set. He dashed out of his house into the street

(so the story goes, and I haven't the heart to cast doubt upon it). "I have seized the light! I have seized the light!" he cried to the passers-by. "In future the sun himself will draw my pictures!" That was not quite a hundred years ago.[1]

What had happened to Daguerre's plate (it was of copper with a thin coating of silver) was that the vapour of some mercury kept in his cupboard developed the *latent* or hidden image imprinted by the light. The atoms of mercury vapour attached themselves to the plate on those parts where the iodide of silver had been decomposed by the sunlight. But Daguerre had so little understanding of chemistry that it took him a long time to trace the result to the dish of mercury that chanced to be in his cupboard.

Louis Daguerre was really very lucky. The French Government gave him a big reward, and the use of his process soon made him well-to-do. And now I must tell you about just one more explorer in this realm of light and lenses and mysterious chemicals. It was an aristocratic Englishman this time, Henry Fox Talbot, who had this ambition in common with the Frenchmen I have told you about; he, too, wanted to capture the delightful picture of the camera obscura. Curious, is it not, that it should have been the *images* of scenes, rather than the scenes themselves, that gripped the imaginations of these pioneers in photography? Though he was pursuing the same goal at the same time, Fox Talbot knew nothing of the discoveries of Daguerre.

Six months before the latter's process was made public Fox Talbot read a paper to the Royal Society in which he described his method of making sun-prints of things like

[1] The process was made public in 1839, a year or so after Daguerre's discovery in the cupboard.

fern-leaves on paper treated with nitrate of silver. A few years later he was taking real photographs in a camera. His method was a better one than Daguerre's and differed from it in a very important particular. When Daguerre took a photograph on one of his metal plates, there could be only one single picture of the subject of any exposure. Talbot took his picture on a piece of sensitized paper. After exposure and development, he oiled the paper to make it transparent. To this transparency Talbot gave the name *negative*, and by placing it in contact with another sheet of sensitized paper and exposing it to light he secured a *positive* print. Thus he was able to make as many prints as he liked from any of the original photographs. Another Englishman, a sculptor named Frederick Scott-Archer, in 1851, gave an immense impetus to photography by substituting glass plates for the sensitized paper that had to be oiled to make it transparent. The plates were coated with collodion, a liquid obtained by dissolving gun-cotton, and then immersed in a bath of nitrate of silver. It was a very messy business, for the photograph had to be taken while the plate was still wet, but it greatly reduced the time of exposure in the camera. The dry plate, on which the light-sensitive chemicals are held in a thin film of gelatine, did not come in until 1878.

Henry Fox Talbot

Silvered copper, paper, glass; and after that a revolution in photographic methods that put cameras into the hands of everyone. Niepce was a civil servant, Daguerre a scene-

painter, Fox Talbot a wealthy gentleman with a taste for drawing, Scott-Archer was a sculptor. The man who made photographers of us all was a bank clerk to begin with, dismissed from his post, so it is said, because his fingers were permanently stained with photographic chemicals. His name was George Eastman, and it was he who, having perfected a method of making a thin transparent film of celluloid, set to work to produce cameras in undreamed-of quantities. In making our Kodaks for us he acquired an immense fortune, most of which he gave away in the causes of charity and higher education. You are not to suppose that Eastman invented celluloid. What he did was to perfect a machine for making rollable transparent films. Celluloid is a very tame kind of gun-cotton—not explosive at all. Gun-cotton is made by treating cotton, or any kind of the vegetable substance called cellulose,[1] with nitric acid. Like the collodion Scott-Archer used, celluloid is gun-cotton treated with a solvent to make it liquid, and then mixed with camphor and other things to make it safe. So far from exploding, modern celluloid is even reluctant to burn!

And now that photography is a mere matter of pressing a button, and we have no need to worry about the why and the wherefore of what we do, the world is inevitably flooded with bad photographs—films over-exposed or under-exposed; fogged, messed-up in developing, spoilt by careless printing. Odd, don't you think, when every process has been brought to a marvellous pitch of technical perfection? Well, a little more care, a little more understanding of what happens inside our cameras, say a shilling or two invested in a simple guide to the chemical action of light, and the reproach of a bad photograph can soon be avoided.

[1] Cellulose is the material secreted by plants for making the walls of their cells and the hard parts of their tissues. It is most easily obtained from cotton and wood.

Let us turn to some of the uses of photography that are less depressing than most of our snapshots, because they are not allowed to go wrong!

CHAPTER X

Wonders of Photography

There are hundreds of applications of the camera that are so peculiar that only specialists know them to exist. Yet it may be said that there is no material thing that cannot be photographed. The uses of photography are applied now to the most intricate and puzzling problems of science. The physicist photographs the wave-lengths of the radiant energy given out by different kinds of atoms, and the tracks of the unthinkably minute bullets, called alpha-particles, that are shot out by radium and the other radio-active atoms. (See p. 203.) This latter is indeed one of the most marvellous achievements of science. It is not easy to photograph the flight of an ordinary bullet, which has a speed of about a mile a second. How much more difficult, then, to photograph the flight of an alpha-particle (which is so small that its size conveys no meaning to us) with a speed 10,000 times as high. Yet photographs have been taken by Professor C. T. R. Wilson which clearly show the tracks of the alpha-particles through a moisture-laden gas, and even the electrons knocked out of atoms of the gas when they were hit by the rushing particle.

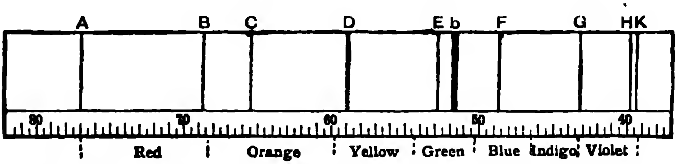
The modern high-speed camera can seize the image shown to it in such an incredibly short space of time that it has become a most valuable instrument for measuring intervals. I wonder if it has ever occurred to you how hard

it is to time anything accurately. Take a race; imagine yourself at the starting-point with one stop-watch, and a friend at the winning-post with another stop-watch. Can you be quite sure that you set your watch exactly when the race starts, or that your friend sets his exactly when it stops, or that your watches are going at exactly the same pace? It takes time for a signal to travel from your eyes or your ears to your brain, and for your brain to send its message to your hand to set the stop-watch. We can't get over that " time-lag " and the faster the event we want to time the worse the time-lag becomes. High-speed events, like seaplane races, are timed by a " camera-gun ", for it is found quite impossible to time them by ordinary human means even with the help of the finest stop-watches. With a seaplane travelling at 300 miles an hour an error of a fifth of a second represents about three miles an hour. So the races or speed trials are timed by electrically controlled cameras and clocks. The clock at each end of the course takes a photograph of itself at the instant when the seaplane reaches a certain mark, and it photographs the mark and the seaplane as well—all in a fraction of a thousandth of a second.

We saw in a previous chapter that the camera can show us pictures brought to it by objects that we cannot possibly see because the radiant-energy they give out is composed of wave-lengths to which our eyes are insensitive. Attached to the microscope and the telescope the camera has brought to our sight a vast multitude of things, things infinitely large or infinitely small, that have enlarged the boundaries of science to an extent such as no scientists could dream of a century ago. In fact, the very existence of the waves of energy beyond the visible spectrum was originally discovered through the effect of the ultra-violet rays on a photographic plate.

Another way in which photography is playing an im-

mensely important part in modern science is in spectroscopic analysis. In the rainbow and in the coloured band produced by a prism we *think* we sec seven colours. But in the spectroscope we can examine the spectrum a little at a time by allowing light to pass through a very narrow slit, colour by colour as it were, and using a lens to magnify what we see. And then it appears that there is really an infinite number of colours, that merge into each other.



Solar Spectrum, showing where the infra-red and ultra-violet rays commence. The scale numbers give the wave-lengths in millionths of a centimetre. The letters are used to indicate prominent absorption lines (see page 129). The spectrum of incandescent sodium vapour always shows two thin yellow lines of exactly the same wave-length as the twin black lines at D. The line A belongs to potassium, C and F and G are hydrogen lines, b that of magnesium, and so on. Characteristic absorption lines are shown on the plate of the spectra in the frontispiece.

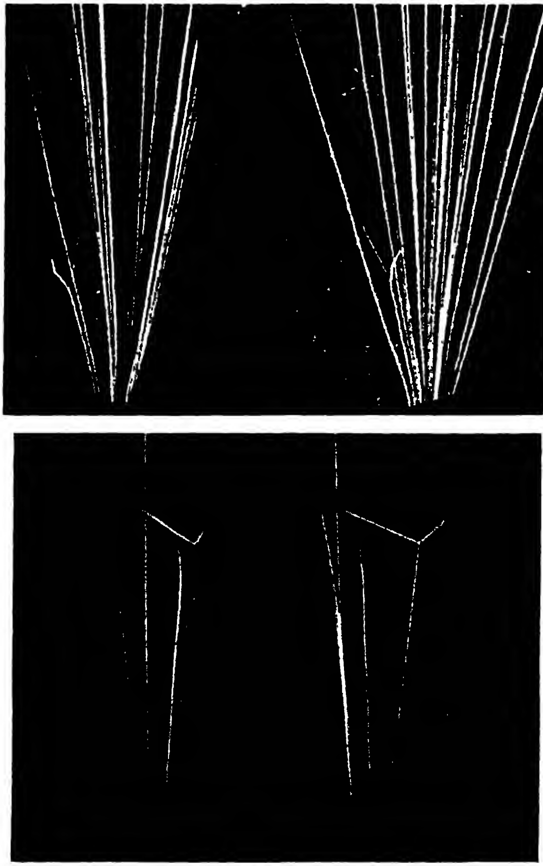
There is a different colour for each wave-length, i.e. each separate energy-squirt, and there is an infinite number of wave-lengths. Now when the solar spectrum is photographed by very exact apparatus it is seen that some of the colours are missing; something has happened to some of the energy-squirts—some of the wave-lengths—so that, instead of bringing us a colour, there is nothing where that colour ought to be. " Nothing " means no radiation, and no radiation in the visible spectrum means no light; consequently the missing wave-lengths are shown on the photographic spectrum as dark lines. There are tens of thousands of such lines, called *absorption lines* on the solar spectrum.[1] The exact positions of the most important of them have been

[1] These dark lines were first discovered at the beginning of last century by Dr. Hyde Wollaston, whom I told you about in Chapter VIII.

accurately measured and they can be compared and identified with the light from any other source besides the sun.

I want to help you to see why their ability to photograph the spectrum places in the hands of scientists a mighty instrument for examining and controlling the particles of matter. It enables the chemist and the physicist (and through them the manufacturers of all the things we use) to say what atoms are where, and what they are doing in any given set of conditions. We have seen that whenever atoms are stimulated—tickled or " gingered-up "—in a particular way, they emit energy in radiations of a particular wave-length. (I am hoping to tell you how they are believed to do this in Chapter XV when we come to look at electrons.) But not only do atoms *emit* radiation; they also *absorb* it—very fortunately for the world. If the atoms of matter were not able to catch and store up energy in some way there would soon be no energy left! The truly amazing thing is the manner in which atoms catch the energy radiated upon them. An atom can only catch and absorb energy when the energy-squirt is of the exact kind and quality to suit its condition. To put this another way, we may say that an atom can never pick up energy unless the energy comes to it in radiation of the precise wave-length to which it responds.

It is just the same as tuning your wireless set. Or imagine a hundred children, each of whom would catch a ball, without any possibility of missing, if the ball was of *exactly the right colour*. Suppose now you had some sort of gun that discharged at these peculiar children an enormous number of balls of a hundred different colours. Each child would catch only those balls that were of its own chosen colour. A child that could catch mauve balls would never miss a mauve ball, but it would not attempt to catch the balls of any other colour. Now think of the children as a mixture of atoms.



Photographs of the tracks of alpha-particles, showing (top) a collision with the nucleus of a nitrogen atom and (bottom) with the nucleus of an oxygen atom. In each case there are two photographs, taken simultaneously, but from different angles, by an electric spark. See page 125.

These wonderful photographs taken by Mr P. M S. Blackett by Professor C T R. Wilson's condensation method show what happens when alpha-particles hit the heavy nuclei of atoms Alpha-particles, the positively-charged "projectiles" shot out by the disintegrating atom of radium, are themselves the nuclei of helium atoms, one of the lightest of the elements. They travel with a speed of some 10,000 miles a second, though they are only measurable in million millionths of an inch The photographs are taken by one of the most beautiful instruments known to science. The alpha-particles are made to traverse a chamber containing moist air which is suddenly cooled The atoms of the gases in the chamber become electrically charged by the passage of the alpha-particles, and on such charged atoms the water-vapour condenses in minute droplets These droplets are so small and so close together that the camera records the tracks of the alpha-particles creating them as white streaks. Each streak shows the track of an alpha-particle "fired" into the chamber. They mostly pass straight through the atoms of the gas, merely knocking electrons out of their way, because the atom is mostly empty space. But one alpha-particle in thousands comes into collision with the heavy nucleus of an atom, and when that happens the nucleus flies off at a tangent, like a billiard ball hit by another ball. By permission of the Royal Society.

Think of the gun that discharges the balls as a source of radiant energy like the sun or a house on fire, and think of the balls themselves as energy-squirts of different wave-lengths; you may now see that when radiation is poured upon a mixed collection of atoms, it is only certain precise wave-lengths (and consequently particular colours) that can be absorbed by the atoms having a liking for such wave-lengths. All the other wave-lengths pass on as unabsorbed radiation.

That is why the dark lines in the spectra of the sun and other stars are called absorption lines. They represent radiant energy that does not reach us at all because it is absorbed by atoms between its source and the spectroscope —actually by the atoms of gases in the sun's envelope that are at a much lower temperature than the atoms emitting the energy. But we have a means of finding out to what elements the atoms belong that produce the dark lines. We can make our earthly gases and solids incandescent and study their spectra. We find that all the substances examined by the spectroscope have quite characteristic spectra by which they may always be identified. Each chemical element gives a *bright* picture of some particular colour, or range of colours, that fits very beautifully into the places where the dark lines occur in the continuous spectrum of the sun. So it comes to this, that it is possible to tell what things are made of, just by sorting out their light. Of course, the study of photographs of their spectra tells us a great deal about the sun and the distant stars.[1] But it also enters very largely into the practical everyday work of research chemists, since it tells them so much about the identity and behaviour of the atoms in the substances they wish to analyse.

[1] The astronomer learns all sorts of unlikely things from spectrum analysis; not only what the sun and other stars are made of and what is happening to their atoms, but whether they are moving nearer to or farther away from the earth, whether they are rotating, how much they weigh, and how far away they are.

I will give you a practical example of this. Ordinary glass shuts out ultra-violet rays almost as completely as bricks and mortar shut out ordinary visible light. But there are particular kinds of glass which transmit the ultra-violet rays along with the visible rays, and such kinds of glass must be as free as possible from the element iron. Iron, however, is not at all easy to get rid of, for it exists in nearly everything, sometimes in such minute quantities that it is very difficult to trace. The spectroscope can discover iron—or any other element—when it is present in such small proportions that all other methods fail to discover it. It can say to the glass-maker, " This sand won't do for ultra-violet glass, for it contains 5/10,000 of one per cent of iron."

When all is said and done, however, the chief interest of photography lies in its pictures of the tangible everyday things around us, the pictures of the hosts of objects, animate and inanimate, that fill our friendly and familiar world. Just think what the word illustrations means! We certainly ought to understand how these illustrations come before us.

Let us take the simple line-drawing first of all—a picture composed entirely of black lines and white spaces. You may recall what I said about Niepce's early experiments with bitumen and oil of lavender. He coated a metal plate with bitumen, and on a piece of glass or a piece of oiled paper he drew a design in black lines. When this design was placed in contact with the bitumen-coated plate and exposed to light, the black lines stopped the light from reaching the bitumen, so that it remained soluble in oil of lavender. It could be dissolved away, down to the metal plate; but where the light had penetrated the glass—where there were no lines—the bitumen was rendered insoluble. Thus the original drawing was transferred to the bitumen plate in a system of grooves and ridges—grooves for lines;

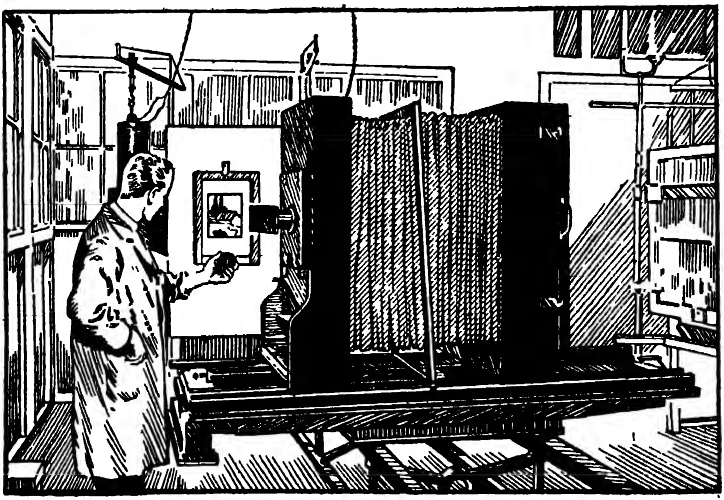
ridges for the spaces between them. If Niepce had inked his plate and printed from it, he would have found his picture in white lines on a black ground.

Such a picture would not be of much use to anyone, yet the principle is exactly the same as that used by the modern block-maker for ordinary black and white drawings. He no longer transfers the drawing directly to the metal plate, however. He first of all takes a photograph of the original; he makes a negative—a reproduction in which the blacks and whites are reversed. Then, when this negative is placed in contact with a metal plate coated with light-sensitive chemicals (compounds of silver soon supplanted bitumen of Judea) light will once more reverse the blacks and whites. The black parts of the negative protect the chemicals on the metal; the clear parts let through the light to make the chemicals insoluble. The soluble parts are then washed away, leaving the unprotected metal free to be eaten away by an acid bath. Thus the protected parts remain unaffected by the acid; they appear as ridges on the metal, and when ink is applied to them they exactly repeat the black lines of the original drawing.

The block-maker's camera is rather a peculiar one, for the lens does not point straight out in front but looks round the corner, so that it is really at right angles to the plate. This is because the picture to be photographed must be reversed, and to do this it is necessary to introduce a mirror or a prism between the picture and the plate. The object of the reversal is to get the picture the right way round when it is finally printed. In an ordinary negative the right-hand side becomes the left hand, but it becomes reversed again when the positive print is made. The block-maker takes a negative, from which he prints a positive—the metal block. But still another printing has to be made, this time with

ink on paper, and you can see that this printing would be the wrong way round unless the picture had been previously reversed, so that it was actually the *right* way round in the block-maker's negative.

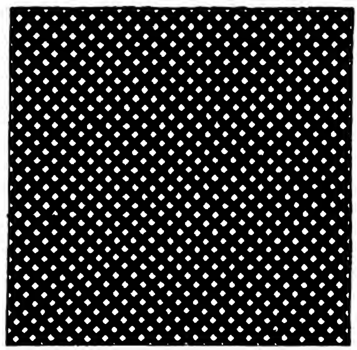
The reproduction of photographs presented a much more difficult problem than the simple process just described.



A Block-maker's Camera photographing a Picture

How was the block-maker to convey to a metal plate the infinite grades of relief needed to reproduce in a printing machine all the half-tones—the varying lights and shades—seen in a photograph? It was necessary that the different parts of a block should accept ink in just as many proportions as there were different degrees of light and darkness in the original. The means by which the necessary variations in relief are given to the block are most interesting and ingenious. The photograph to be reproduced is first divided up into an enormous number of very small sections. Each of these sections will be represented on the printer's

block by a dot that will take up the ink exactly in proportion to the light that reached it in the camera. To break up the picture into these myriad dots, the block-maker photographs the photograph through a "process-screen", a glass plate ruled with a network of fine lines. If you will look very closely at any of the photographs in this book, you may see how the process-screen has split up the picture into dots. Some of them are very large, some very small; there are dots of all sizes, up to the limit set by the close-ruled network on the screen. One of the illustrations shows part of a half-tone reproduction much enlarged to show how it is divided into this complicated system of dots. In the block-maker's camera, the light reflected from the original photograph passed through the process-screen and darkened the negative exactly in proportion to its intensity in different parts of the picture. You see how the screen divided it up into a vast number of separate energy-impulses, each of which brought its own message to the plate. And so, when the negative was printed in contact with the metal block the lights of the picture were resolved into little dots, the shadows into big ones. Then the acid bath ate away the soluble parts where the light could not penetrate the negative—the high-lights—"etching" or engraving the block in corresponding relief.

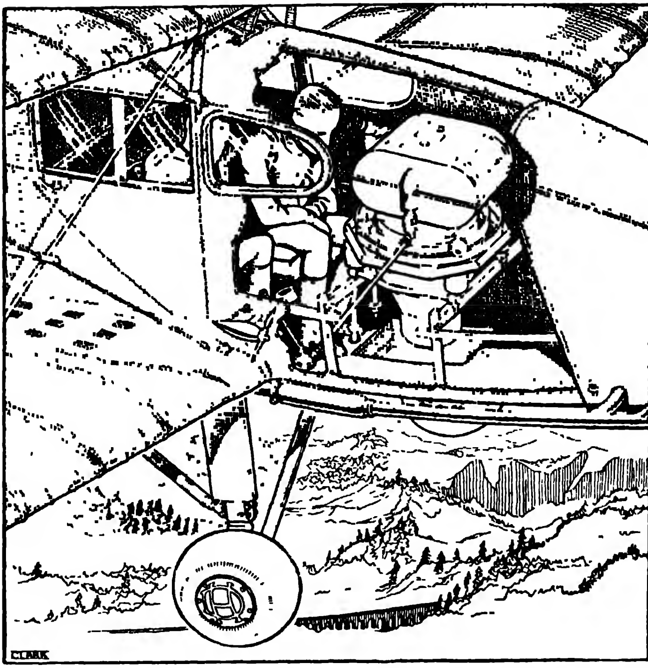


Enlarged view of a part of a process-screen. The screen consists of two ruled sheets of glass sealed together with the rulings of one sheet crossing these of the other at right angles. In the screen for the half-tone blocks for the plates in this book there were 175 lines to the inch. That means there are 30625 dots to the square inch.

A print of an enlarged impression of a half-tone block of a child's face. It shows how the dots preserve the tones and at the same time ensure a practical printing surface because the inking roller only comes in contact with the dots and are therefore the only portions of the block capable of leaving their impression on the paper. Look at the picture from a distance and as the screen becomes lost the continuous tones of the original photograph can be seen.

I am going to close this chapter by telling you something about two uses of photography that have become very important in a surprisingly short time. I expect you have seen photographs of towns and cities taken from aeroplanes. I dare say you felt, as you looked at such pictures, that they showed you familiar things—houses, churches, streets, squares, parks—in a manner that was very interesting because you saw them from a new angle. It is just for this reason that photographs taken from the air can be very useful to those whose task it is to discover how the streets and buildings in our towns can be more conveniently planned. And there are many other ways in which air photographs are of real practical use. The camera is very sensitive to colour; for there are differences in the wave-lengths of ordinary light that the camera can detect—not in colours, but in shades of black and white—although these differences are not perceptible to human sight. Photographs taken from the air reveal variations in the colours of woods and fields, rocks and soils, that the eye cannot possibly distinguish. Perhaps you think that such variations cannot be of much importance to anyone; if so, you are wrong. The people whose business it is to study the different kinds of rocks and soils can tell from aerial photographs whether the ground depicted is fertile or infertile; they can even say, sometimes, what kind of treatment is needed to make the infertile kinds more productive. The pictures also tell them what minerals may be hidden beneath the surface.

The taking of aerial photographs is a very important part of the new science of aerial surveying. I expect you know how, in the ordinary way, surveyors map out a region, acre by acre and mile by mile, after they have measured it out by using an instrument called a theodolite. That is a



Photographing from an aeroplane (the fuselage is cut away to show the camera) Notice the little propeller at the side which drives the camera.

very long and tedious business. Think of the vast stretches of country in Africa and Asia in which that kind of surveying would take years and years to accomplish. Now, thanks to the aeroplane and to the inventors of special kinds of cameras, it is possible to make accurate photographic surveys in a hundredth part of the time. The planes, fitted with suitable cameras, fly over the country to be surveyed, strip by strip. There are usually two cameras. One takes slanting photographs of the country, the other looks straight down at the ground. An electric control exposes the film at regular intervals and winds it on for the next exposure.

The usefulness of air surveying has lately become very

E 712

INFRA-RED PHOTOGRAPHY

The cliffs of Dover from the coast of France. Although the cliffs of Dover ("the white walls of old England") are visible from the French coast, it is only on the very clearest of days that any of the prominent landmarks may be distinguished with the naked eye. In this view, taken from a point near to the lighthouse at Cape Gris-Nez, details of the English coast, which is close upon 20 miles away, are clearly seen, and it provides a striking illustration of the use of the Ilford infra-red filter and plate and the long-focus lens. The stretch of coast shown in the picture is from Shakespeare Cliff on the extreme left to St Margaret's Bay, a distance of about 5 miles, and it will be observed that Dover Castle and details of the Admiralty Harbour at Dover are visible.

much increased by the perfection of cameras, lenses and plates for taking photographs by infra-red rays. To understand just what this means we shall need to remind ourselves again of the wave-motion of light. Excited atoms send out pulses of energy that travel onwards as waves of all sorts of frequencies or wave-lengths, of which only a few affect our eyes, so that we can recognize them as light.[1] Beyond the violet end of the spectrum there are waves that become shorter and shorter; some of these very short waves we make use of as X-rays. Beyond the red end of the spectrum there are waves that become longer and longer; these are infra-red waves, then heat waves, finally the very long waves used in wireless. Now, I want you to understand that infra-red photography is really and truly photography *in the dark*. It is quite possible to take excellent pictures in a perfectly dark room, with suitable apparatus, using instead of ordinary light the rays from a special kind of electric lamp that only gives out energy of the longer wave-lengths that our eyes cannot detect.

There is something very strange in this, I think you will agree; something that upsets all our common ideas of photography. Why, the ordinary photographic plates and films are even insensitive to the red light visible to us! We develop our pictures by the light of a red lamp—those of us who still do any developing! Every photographer knows that ordinary photographic films are only sensitive to visible blue and violet light, though by special treatment they may also be made sensitive to green light. How is it possible to make the camera see by rays of red " light " far beyond our own range of sight?

A wonderful story of scientific exploration lies behind the answer to that question. It took years of research in the

[1] A table of wave-lengths is given on p. 127.

laboratories of a British firm of plate-makers, who succeeded at last in finding a substance (a very complicated kind of dye) that makes plates sensitive to the infra-red rays. Then, new kinds of camera lenses had to be devised, for these rays must be bent to particular angles of their own before they can be focussed. Next, a screen was needed —a suitably coloured " filter " to shut out all the wave-lengths except the infra-red—to make it possible to take infra-red photographs in ordinary light.

The particular value of infra-red photography in air-surveying lies in the extraordinary penetrative power of these rays. If you take a distant view with an ordinary camera the result is almost certain to be disappointing, except on the very rare occasions when the air is very dry and very clear. Even when the air looks clear, and you can see a long way, it contains moisture to twist and bend and absorb the light rays. But infra-red rays are much less affected by the atmosphere. They can even penetrate mist and fog.[1] This means that the pilot can fly at a much greater height, and the higher he is the greater the area of ground within the view of his camera. Perfectly clear detail has been secured in infra-red photographs taken from a height of 20,000 feet, and it is now possible to take " snaps ", by this process, of scenes twenty miles away and more.

We have skimmed over the great science of photography, but we have not even glanced at some of its most important uses. What about X-rays? And what about the cinema? We will let them have chapters to themselves, these very important kinds of light-writing. But we shall not make much of them until we understand something of electricity; the science of sound, too, we need to make the talkies. So we must pick up the photographic trail again, a little later on.

[1] But not dusty or sooty fogs such as hang over cities.

CHAPTER XI

Science of the Air

Most of us take a great deal too much for granted. Air is the first necessity of life—a more urgent necessity even than water or food—but so long as we do not feel noticeably in need of it, we seldom give the subject a thought. What is even worse, we are sometimes so indifferent to it that we allow our lungs to inhale stale air, overheated and overcharged with the waste products of other people's lungs. Not a nice idea, is it?

"As free as the air we breathe," we say, but we do not realize that unless we live in the country, away from other houses, the air we breathe is not by any means free, except in the sense that no money is directly paid for it. The air of towns is obliged to carry away the exhalations of all the townspeople, the smells and poisonous waste gases of all the motor-cars, and in addition the smoke of countless fireplaces and, very often, of factory chimneys. Well, it just cannot do it (by and by we shall see why), and the result is that the townspeople have to keep their smells and their stuffiness, and the outsides of all the buildings become covered with grime and soot, and the grime and soot enter through windows and doors and soil the insides of the buildings and, very frequently, the insides of people's lungs as well. Then in the winter-time, when layers of cold air press downwards over the town, reeking fogs engulf the streets and further damage the lungs of the town-dwellers.

So we ought to be very grateful for the Acts of Parliament which decree that air is not "free" for anyone to fill with as much filthy black smoke as he likes, ruining the

buildings and spreading disease amongst the inhabitants. People whose memories go back twenty or thirty years can notice a wonderful difference in the atmosphere of cities. The air is clearer, the views are brighter; and when we approach a city by train or car there is no longer such a heavy cloud of smoke hanging over it and staining all the horizon. The reason is that in many towns factories are compelled to use smokeless fuel [1], or to stoke their furnaces in such a way that the fuel is more completely burnt; while the great strides made in the use of electricity further help to reduce this great evil. Factories that cannot avoid making a great deal of black smoke can be compelled by the by-laws of their towns to restrict their smoke-making to certain hours of the night, so that the life of the town can go on during the daytime in an atmosphere which can be penetrated by sunlight.

But much still remains to be done, and we ought not to rest until the smoke nuisance is really and truly banished from our midst. We cannot help the waste gases that come from people's lungs—the products of the combustion that keeps our bodies going—but we can and must learn to avoid fouling the atmosphere with all other kinds of imperfect burning. It's not enough to insist that factories shall not make smoke; everyone who burns raw coal in the old-fashioned kind of grate does a little towards darkening his town and destroying its buildings. Coal simply *cannot* burn properly in an ordinary open grate, for the reason that it can never obtain enough oxygen for complete combustion. It is very wasteful and extravagant because more than half the heat-giving material goes up the chimney unburnt, to make soot, smoke, fog, and *sulphurous-acid gas.*

[1] It is not entirely smokeless, but gives off comparatively little in the way of black fumes.

When it rains, this gas, like the other gases of the air, becomes dissolved and the solution so formed eats into the stonework of our buildings and gradually destroys them. Fortunately the remedy for this deplorable blot on our use of everyday science is a fairly straightforward one. Those of us who are unable to heat our houses by gas or electricity or "central heating" must see to it that the fuel is really burnt and not merely half-burnt. And the fuel itself should be of the smokeless kind, rendered less harmful and more economical by having some of its products taken away before we put it on our fires.

But what is this free commodity called air, which is vital to life in plants and animals? Although invisible, it possesses weight and substance, and it is necessary for the transmission of sound. You are going to say that air is a gas, but that is not quite the right thing to say. Air is a mixture of gases—it is composed of the molecules of a number of different gases that are not chemically combined with each other. The composition of what we may term ordinary air—that is to say outdoor air which is neither excessively dry nor excessively moist and is free from pollution by smoke—is four parts by volume of nitrogen and one of oxygen, with less than 1 per cent by volume of argon, and quite small quantities of carbonic acid gas and water vapour. Other gases, including helium, occur in minute proportions. These other gases may be difficult to detect in air but are revealed by analysis of rain-water, in which they dissolve as the rain falls. Now the important ingredient for animal life is, of course, the oxygen which is inhaled by all forms of animals; but plants make use of the carbonic acid and exhale the oxygen; thus the two forms of life on the surface of the earth keep the balance between these two gases of the atmosphere fairly evenly.

I say "fairly evenly" because we should hardly expect the mixture of gases to be everywhere quite the same. In the air over oceans and deserts we should expect to find more carbonic acid, because in such places there are no plants to use it up, and in great forest regions there ought to be more oxygen in the air. That is exactly what we do find, though the difference in proportion is not very great.

We should also expect to find in a mixture of gases that the heaviest molecules gravitated to the bottom of the mixture. So they do. Half the total weight of the air forms a layer on the earth only three or four miles thick. We do not exactly know how high above us the atmosphere extends, but it is certainly more than a hundred miles thick, probably much more. The higher up we go the thinner the air becomes, until in the upper layers it is composed mostly of the very light gases hydrogen and helium. The heavier oxygen and nitrogen are densest in the lowermost layers. Man and the higher animals cannot live for long at a height of 17,000 feet above sea-level, owing to the want of oxygen. At 20,000 feet, the air contains only half the normal proportion of oxygen—10 per cent instead of 20·9 per cent. The purpose of the nitrogen in the air is to dilute the oxygen to make it safe to breathe. The oxygen enters into chemical combustion with the sugar in our blood, and all our energy is derived from this process of slow combustion. Each time we take a breath, our lungs inhale enough oxygen to feed the blood and enough nitrogen to regulate the burning that keeps our bodies going. If there is too little oxygen the burning is too slow, while too much oxygen makes the burning too fast.

I have said that air always contains more or less water in the form of invisible vapour, and there is another constituent that we must not overlook—dust. Even the purest

air contains fine particles in suspension, as any sunbeam will show you. This dust, in spite of the horror with which it is viewed by housewives, may have quite a romantic history. It is largely meteoric fragments broken off from those fascinating visitors which reach the earth to the amount of many thousands of tons daily, ground to the finest powder by the friction of our atmosphere.[1] The air also carries a great deal of volcanic dust. Part of the dust we are now breathing may be the product of some eruption perhaps two thousand miles away, which is slowly circling round the earth. The air also contains spores of mildews and moulds, and the germs which set up putrefaction in meat, and unfortunately disease germs as well. Without this dust in the atmosphere, our sunlight would be very hard and clear, and we should have few of the beautiful gradations of colour in the sky which we look for so eagerly at night and morning. Even the blue of the sky is dependent on dust, which breaks the rays of blue light coming from the sun. Water vapour, mist, and cloud also have some part in the pageant of the sky. Water vapour condenses when it comes in contact with a surface colder than itself, and the dust in the air provides such surfaces and so enables the water vapour to condense into water. Clouds are made up of minute water droplets, each with a speck of dust at its centre. In smoky industrial districts, where the dust particles are sooty and greasy, fogs are made in this way.

We must not forget that there are many different kinds of dust made by different industries, and some diseases of the kind known as "occupational diseases" are caused entirely by the harmful dust which the workmen have to inhale. For instance, metal workers spend their working

[1] See footnote on p. 69, Chapter VI.

hours in an atmosphere laden with fine particles of sharp metal dust which are terribly injurious to the lungs, and stone-masons are constantly inhaling stone dust which is almost as dangerous. In both these trades the proportion of sufferers from consumption is appallingly high.

A page or two back we spoke about the weight of the air —the pressure it exerts on the surface of everything encompassed by it. We actually take the weight of the air every time we look at the barometer, but it is more usual to talk about the *density* of a gas than about its weight. I told you what was meant by density in Chapter III (p. 36). The density of the air depends on its temperature. Warm air is lighter than cold air. It expands; the molecules move farther apart, so that in a given volume, a cubic foot say, there is less air than there would be at a lower temperature. The expanding air rises upwards, its place being taken by denser air. The unequal heating of the atmosphere by the sun makes winds and so gives the earth its different kinds of climate. Rain and snow are due to the fact that air can hold great quantities of water vapour. Moist air is lighter than dry air at the same temperature, and the amount of moisture air can contain depends on how warm it is. It is on these two very simple facts—that warm air is lighter than cold air, and moist air lighter than dry air—that we arrange the ventilation of our houses. More often than not, perhaps, the ventilation arranges itself without any effort on our part, but that, you will agree, is not as it should be. This is the A B C of ventilation. Air is heated and moistened by passing through our lungs and rises upwards, carrying with it the carbonic acid gas we have exhaled. Then we open a window at the top and the heated air passes outside. Cold air continually enters the room by means of the space under the door, or round the door and window frames, and as

fast as the warmed air leaves by the opening at the top of the window, fresh cold air comes in to take its place, so that the amount of air in the room remains the same. The smaller the opening through which the cold air has to pass the faster it comes, and that is why people feel a draught when the door or window is open only a very little way, and do not complain when it is widely open. So long as fresh air can find its way freely into our rooms, and the stale air can find its way out, there is nothing much amiss with our household ventilation, though we must take care that the heat we have to supply in winter is not carried away by draughts.

But in big buildings frequented by multitudes of people, the problem is much more difficult. Take the case of a cinema or a theatre or a large restaurant. In any such place it is very necessary to maintain a constant supply of fresh air. Thousands of people are using up the oxygen and breathing out carbonic acid gas, and so are their pipes and cigarettes. The stale air becomes heavily laden with germs and dust, and is then most unwholesome. In the days not long gone by, when the science of air was not properly understood, people wondered why they felt faint and sick in crowded places. Now that we know how important a part fresh air plays in keeping us healthy there is no excuse for ill-ventilated buildings. Fortunately a robust and flourishing young science is now devoted entirely to this subject, and a special branch of engineering makes the necessary apparatus for ensuring a pure air supply in large buildings. Some of the modern ventilating systems are very ingenious and complicated. The air is drawn from outside the building and then filtered and purified, either by an electrical process which kills the germs and precipitates the dust, or else by passing it through a curtain-like arrange-

ment of water-jets. It is then warmed and pumped into the building while the stale air is being sucked out.

I have spoken once or twice of carbonic acid gas. We ought to know something about this gas which enters so largely into our lives. It is also called carbon-dioxide, and its chemical symbol is CO_2, which means that its molecule is composed of two atoms of oxygen linked to an atom of carbon. Whenever anything is burnt this gas is one of the products of the burning. It will not burn, and nothing will burn in it, so one way by which fires can be put out is to smother them with something that liberates carbonic acid gas. If the fire is a very little one a syphon of soda-water or a bottle of ginger-beer or of champagne will put it out as well as anything.[1]

You might think that as soon as the bottle was opened the gas would become so mixed with the air that it could have little effect on the fire. But it is a heavy gas, so much heavier than air that when it is emptied from a vessel it at once sinks to the floor. I think that may be the reason why cats and dogs often become restless in ill-ventilated rooms. Animals that are usually quite content to lie on the floor when doors and windows are open want to jump upon chairs when the room becomes close and stuffy, and they are in danger of partial suffocation by the exhaled carbonic acid that sinks down to the floor.

While we are speaking of carbonic acid gas I may draw your attention to another gas, also formed by linking oxygen atoms to carbon atoms. You may recollect that when we were talking about atoms and molecules (in Chapter IV) I told you how common salt resulted from the union of an

[1] It is carbonic acid which gives the fizz to drinks. The gas is made when anything ferments, which explains its presence in wine, beer, cider and the like. It is pumped into aerated waters to give them a sparkle. The gas is easily dissolved in water under slight pressure.

atom of the element chlorine with an atom of the element sodium—the one by itself a poisonous gas and the other by itself a dangerous metal. Now, here are oxygen (O) and carbon (C) both quite harmless (in moderation) and, indeed, necessary to existence. When one atom of C is joined to two atoms of O, however, we have carbon dioxide (carbonic acid gas) which suffocates us if there is more than 25 per cent of it in the air. And when an atom of carbon is joined by *one* atom of oxygen, we have carbon *monoxide*, which is a deadly gas to breathe even in small quantities. Moreover, it burns, whereas carbon dioxide puts fire out! So you see what a change a single atom can produce in the nature of things.

This carbon monoxide is such a dangerous thing that no one ought to take risks with it. Yet we are surrounded by it. We may liken it to a malevolent creature our scientific progress has inadvertently set in our midst. As a constituent of coal gas the demon carbon monoxide hisses from every gas-tap. It also rushes from the exhaust pipe of every motor-car. Therefore the smallest gas-leak should be treated as a very serious danger, while a leaky exhaust in a closed car, or a motor engine left running in a closed garage, has not infrequently led to tragedy.

But let us get back to our fresh air. We will see how it can be made to work for us.

CHAPTER XII

Air made to Work

Here comes our old friend Robert Boyle, walking down the street in the grand dress worn by gentlemen in the time of King Charles the Second. Two great masses of carefully curled hair fall over his shoulders, for he is wearing a wig of the kind fashionable in that period. "The Father of Modern Chemistry" has come out to see the town, after many hours spent at work on his "pneumatical engine". Under his arm he carries a book, with a very long high-sounding title. It is called *The Defence of the Doctrine touching the Spring and Weight of the Air.*[1] Robert Boyle has been very busy with the air. His "pneumatical engine" is nothing more than an air-pump! The inventor did not foresee the coming of an age when people should travel on pneumatic tyres, or he might also have foreseen that in time to come a neat and handy little tool, directly descended from his pneumatical engine, would be in the hands of every boy and girl who possessed a bicycle.

To us who make the air work for us in so many ways—holding up our aeroplanes, driving tools and machinery, and so forth—it seems strange that anyone should ever doubt the "Spring and Weight" of the air. Less than 300 years ago it was believed that air had no weight. The great Greek philosopher, Aristotle, who was often right in his reasoning and experiment, once tried to weigh air. He filled a bladder with air and weighed it; then he emptied

[1] It was in this book, published in 1662, that Boyle stated the law, ever since known by his name, that the volume of a gas varies inversely as the pressure (see Chapter III, p. 40). In France this law is called Mariotte's law, after a French physicist, who presented the same conclusions in a book published in 1676. News of discovery took a long time to travel in those days.

the bladder and weighed it again; and there was no difference in the two weights. Therefore, said Aristotle, air has no weight; and all through the ages people never questioned this conclusion. Aristotle did not allow for the fact that both his full bladder and his empty bladder were sustaining an equal amount of air-pressure. Galileo was a little more scientific when he weighed a globe filled with air and compared the result with that obtained when the same globe was filled with *compressed* air, but even he did not appreciate the knowledge he gained when he found that the globe was heavier when filled with compressed air.

There is a very simple experiment that Aristotle might have made, or Galileo or anyone else, that would have shown them that air exerts pressure. You can do it. All you want is a small wide-mouthed bottle, a jug of water, and a piece of paper. Completely fill the bottle with water and press the paper firmly over the mouth; then turn the bottle upside down, holding the paper in position while you do so. If the bottle is really full, and the paper fits properly, you can safely remove your hand. The water won't run out, because the pressure of the atmosphere is greater than the pressure of the water in the bottle. The experiment is more effective if you do it with a tumbler instead of a bottle, using a piece of thin card instead of paper; only don't do it over the best carpet, because it is not very easy to hold the card in contact with the rim of the tumbler while the latter is being inverted.

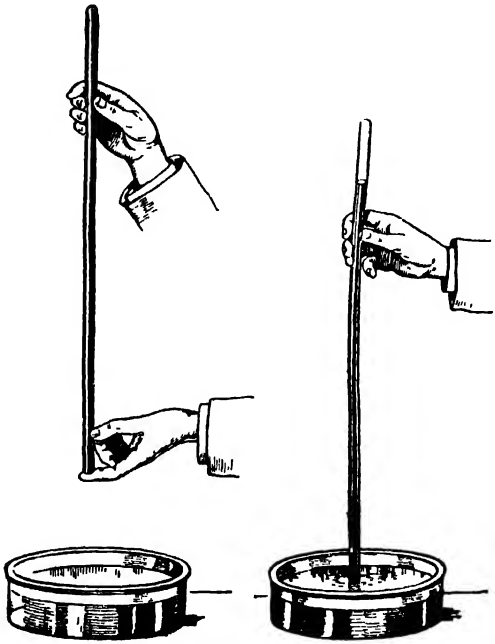
It is clear that in this case the pressure of the air acts *upwards* since it counteracts the pressure of the water, which acts downwards. It acts equally in all directions. The air bears upon everything at sea-level with a pressure of 14·7 lb. to the square inch—about a ton to the square foot. We are unconscious of this great weight upon us because it is

exerted upon all parts of us, inside as well as outside. If we were to be suddenly subjected to greater external air pressure while the internal pressure remained at normal, we should soon be crushed to death, while if enough extra air was pumped into us we should explode. The pressure of the air varies at sea-level from day to day and from place to place. We say " at sea-level " because that is the level at which we feel the full weight of the atmosphere—the lowest level. I told you in the last chapter that about one half the total mass of the atmosphere lies within a few miles of the earth. It follows that if we ascend a mountain there will be less of the total mass of the atmosphere pressing upon us. If you climb a mountain a mile high, only 5280 feet, the weight of the air will be about $\frac{5}{6}$ of that at sea-level, for a sixth of it is below you. If the barometer reads 30 inches at sea-level it will be only 25 inches at a mile high. *Inches of what?* It certainly does seem strange that we should measure the weight of anything in inches—about as sensible as measuring flour by the yard!

This brings us again to the " spring and weight " of the air, that old Robert Boyle found it necessary to defend. It brings us, too, to that much abused and ill-understood instrument by which the spring and weight are measured—the barometer. Let us make a barometer for ourselves. All we need is a supply of the dense liquid metal, mercury,[1] a glass tube about three feet long, closed at one end, and a small dish. We completely fill the tube with mercury, and we also pour mercury into the dish. Then, holding a finger over the end of the tube, so that the mercury cannot escape, we invert the tube and introduce the open end below the surface of the mercury in the dish. What happens? You

[1] Don't take this seriously. The experiment can easily be done in the school lab., but mercury is nasty stuff to have about the house.

might suppose that the heavy metal would fall out of the tube with a flop. Instead it only drops a few inches, leaving a space at the top of the tube. About 30 inches of the mercury "stays put". Now, we started with a tube *full*



Making the simple Barometer called Torricelli's Tube

of mercury, so the space above the mercury in the tube cannot be air. What is it, then? It is nothing. More exactly, there is a little matter in this space, but it is of such low density that we can leave it out of account, and say that there is nothing in the tube to exert pressure on the mercury. It is a true vacuum.

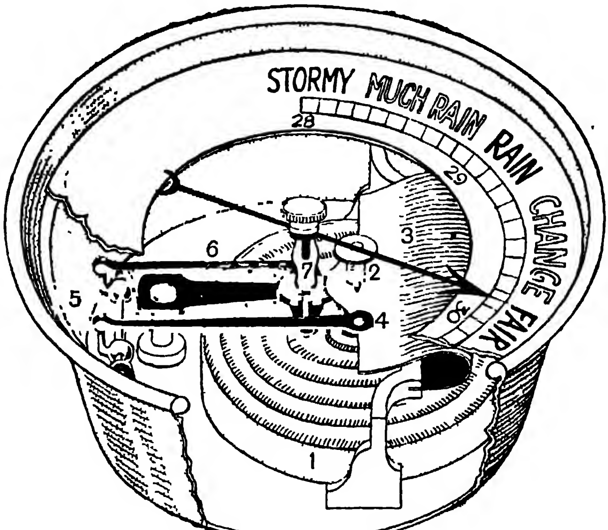
You do not need to be told what force it is that stops the mercury from falling out of the tube and overfilling the dish. The pressure of the air is holding it up. In other

words, the weight of the air bearing upon the surface of the mercury in the dish balances the mercury in the tube. When the pressure of the air is 14·7 lb. to the square inch, it supports a column of mercury exactly 30 inches high. If the air pressure is less (we saw in the last chapter how the density of the air varies with temperature), it will not balance quite such a tall column of mercury; while if the air becomes colder and drier, up goes our home-made barometer. The denser the atmosphere, the longer the column of mercury it can support.

That is where the inches come in. This simple barometer is sometimes called Torricelli's Tube, after its inventor, an Italian scientist of the time of Galileo. Even after nearly 300 years we have no more reliable instrument for measuring the pressure of the atmosphere than a column of mercury.[1] But it is rather an awkward thing to carry about, and so the *aneroid* barometer came into fashion on account of its lightness and portability. Aneroid means " not wet ", i.e. it contains no fluid. The pressure of the air acts upon the elastic sides of a little metal box that has been exhausted of air. A spring in the box prevents it from being squashed flat, while the sides of the box act as a very sensitive spring, the movements of which under the variations of air pressure are much magnified by an ingenious mechanism connected with the index hand. In order that it may be easily compared with the mercurial barometer, the scale of the aneroid is likewise shown in inches—or was, until very recently, for modern barometers are coming out with a more sensible kind of measure, called *millibars*. It is useful to know that 34 millibars equal one inch.

[1] We must not forget that mercury undergoes great changes of bulk with changes of temperature (for which reason it is used in thermometers) and that these changes may mislead us in interpreting those due to pressure. To be strictly accurate, the height of the mercury must be corrected for temperature, but this is not difficult, since we know that mercury increases its bulk by 1/9,900 for every degree Fahrenheit.

Perhaps somebody is thinking that any liquid would make an air-balance. Of course it would. Mercury is the densest liquid we have, and so we need least of it. It is 13·6 times heavier than water, so a water barometer needs a column



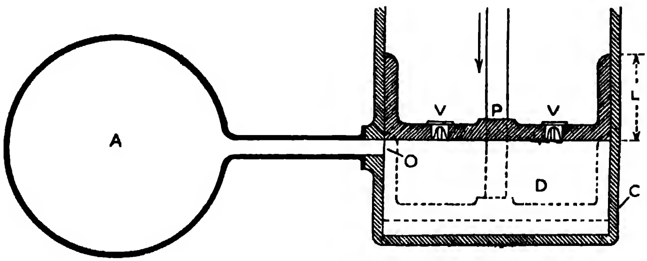
An Aneroid Barometer shown partly in Section

A metal box 1 rises and falls with the varying pressure of the air, and its movement is transmitted by the pin 2 to the spring 3. To this spring is fastened the lever 4, which turns the shaft 5 to which is connected the lever and chain 6. This chain turns the spindle 7 which operates the pointer.

about 33 feet high—rather an awkward length to put in the front hall. But we shall come upon this column of water when we want to bring it up from the well. In another chapter we must look at the common pump, a piece of mechanism which operates by virtue of the weight of the atmosphere. At the moment we must see how the air-pump works by which we can make the air more dense or *compressed*, and so turn it into a most useful source

of stored-up energy, that we can set to work in engines and machinery.

For a start we might do worse than take our bicycle pump to pieces. This consists of a tube, with a nozzle at one end, while at the other is the handle of a rod which can be worked



Sectional View of Air-pump

An ordinary air-pump consists essentially of a cylinder or barrel with a piston and valves. The barrel is connected to the vessel from which the air is to be pumped. A is the vessel to be exhausted, C the air-pump cylinder, P the piston, VV valves in the piston, and O the connexion to the vessel A. When the piston moves downwards from the position shown, it cuts off the connexion with A by passing over O. The length L is made long enough so that O is kept covered up during the downstroke. The air filling the space D is compressed, and so lifts the valves VV and passes out through them. This goes on till the end of the downward stroke, when the volume is very small indeed When the upward motion begins, the valves VV close, and the piston rises and creates a vacuum in D When the piston rises sufficiently to uncover O (as in figure), air rushes from A into the highly exhausted space D and fills it. The process is repeated indefinitely, and A is gradually exhausted.

Air-pumps for compressing air are constructed on the same principle, but the valves act the reverse way. The bicycle pump is a well-known example of this form of pump.

up and down inside the tube. At the inner end of the rod there is a metal disc which fits easily inside the tube. Fixed to the side of the disc nearest the nozzle there is a cup-shaped piece of leather fastened in such a way that the rim of the cup is towards the nozzle. Now, if the nozzle is stopped up with the finger, and the handle, after being pulled out, is pushed inwards, it will be found that the air between the nozzle and the cup is compressed, and it is

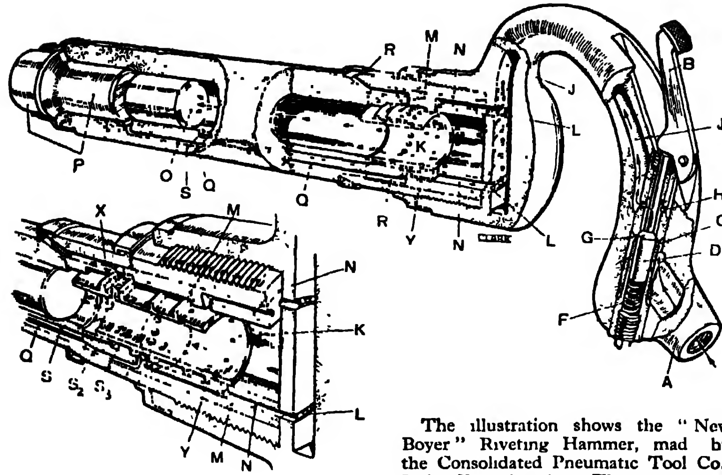
almost impossible to push the handle home without forcing the finger away from the nozzle and allowing some of the air to escape. On the other hand, if the handle is pulled out while the finger is still held tightly on the nozzle, it is found that very little effort need be used, which shows that there is practically no suction. One would perhaps expect that if compression is caused by pushing the handle in, rarefaction and suction would result from pulling it out. This is just what does happen with a garden syringe, but it is the leather cup which enables the air-pump to work as it does. When the handle is being pushed in, the air begins to be compressed and thus causes the rim of the cup to be pressed tightly against the inside of the tube so as to make an air-tight joint, and the more the pressure the better the joint. On pulling out the handle the rim of the cup is sucked away from the tube, and air can come in freely past the cup. In a garden syringe we do not, of course, want the air to come in at the top, as in that case the water would not be sucked up, so we replace the leather cup with a form of washer that makes a good water-tight fit, whether the handle is being pushed in or pulled out.

We do not put very much air into bicycle tyres, but the amount of air we can put into anything depends only on the strength of the vessel that is to contain it and the energy we expend to force it into the vessel. Air has been compressed to about 4000 times its ordinary density, a pressure of something like 30,000 tons on a surface one yard square. But in everyday working the pressure used is very much lower, generally a few hundred pounds to the square inch, for with very high pressure there is always the risk of explosion. The pumps which provide the compressed air for driving machinery work on just the same principle as the bicycle pump, only there are double sets of valves for controlling

the air. A piston moves up and down in a cylinder, and at each stroke the piston compresses the air in front of it. The force of this compressed air pushes open a valve through which the air is sent into a reservoir. As the piston moves forward it creates a vacuum in the space behind it, and the weight of the atmosphere pushes open the inlet valve and fills the cylinder with air ready for the backward stroke of the piston to compress. By having an inlet valve and a delivery valve at both ends of the cylinder, the piston is always compressing air in the direction of its travel.

The power needed to work the compressor can be supplied by any engine—steam, gas, electricity, or even a water-wheel; though, in the last case, it would be better to turn the water power into electric power, and then make an electric motor work the compressor. Sometimes the stored-up energy of water is directly converted into air-power without the use of a mechanical air-pump such as I have just described. The momentum of water falling down a pipe is used to carry down with it a supply of air drawn in through a system of little tubes. During its fall the air becomes mixed with the water. At the bottom of the fall, there is a sudden change of direction, the vertical pipe giving place to a level one. Above the level pipe a chamber is built, into which the air escapes in bubbles of foam. In this chamber it becomes very highly compressed, since it cannot get out by the way it went in.

Many different kinds of tools and machines are worked by compressed air. The growing use of electricity has somewhat reduced the demand for pneumatic tools, for electricity is much more easily and cheaply transmitted than compressed air. But there are still many fields in which air-power is a more useful workman than any other power. Pneumatic tools are very simple in principle, and there are few working



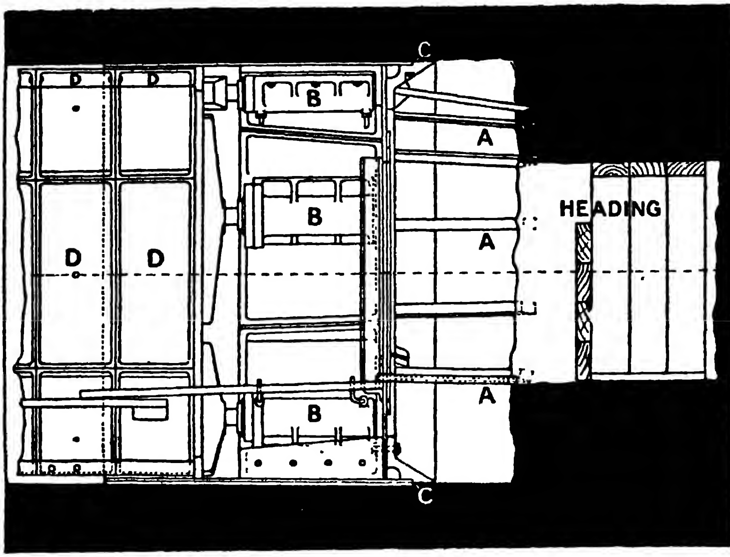
The illustration shows the "New Boyer" Riveting Hammer, mad by the Consolidated Pneumatic Tool Co., Ltd., Fraserburgh The air-pipe is attached to the handle at A. The throttle-valve D is normally kept closed by the spring F, but when it is opened by pressure on the trigger B, the ports G are uncovered, and the compressed air flows through G and H into the passage J. The hammer-valve K is movable. It is shown in its forward position The air flows through J into the groove L, thence through a number of ports N in the valve-case M into the cylinder, through the hammer-valve, where it acts on the rear end of the piston O, driving it forward to strike the working tool, or snap, P. The space in front of the piston is, during this part of the stroke, in communication with the atmosphere through the ports Q and R. As soon as the rear end of the piston has uncovered the port S, air from the cylinder flows through narrow port S_2 and S_3 against rim of hammer-valve, and moves the hammer-valve backwards, cutting off the air-supply N to the back of the piston, but opening a way for it to the front through Y and Q so that the piston is driven backwards. The space between piston and handle is, during this back-stroke, in communication with the atmosphere until the rear end passes a certain point, when hammer-valve cuts off the route to atmosphere. The air still remaining is trapped, and acts as a cushion to prevent shock to operator. When this point is reached, the hammer-valve K is pressed forwards, air enters the cylinder again through the groove N, and another forward stroke begins. The hammer, working at 80 lb. to 100 lb. pressure, gives about 1000 blows per minute.

parts to get out of order. A piston moving in a cylinder carries a rod which projects through an air-tight collar. Compressed air enters the cylinder through a valve and passes along passages bored in the walls of the cylinder to openings at each end. The expanding air, pressing first against one side of the piston and then against the other side, pushes it backwards and forwards with a force that can be adjusted at will from a steady gentle pressure to a

A rear view of the Greathead Shield showing the men at work in it.

Notice the hydraulic rams at the top (B in diagram on opposite page) which drive the shield forward. By courtesy of "London's Underground". See also diagram on opposite page.

The "shield" is pushed forward, foot by foot, through the stiff clay in which the tunnels are made, by powerful hydraulic rams. Gangs of men with picks and shovels, or sometimes mechanical excavators, throw out the clay, which comes through an opening in the shield as it forges ahead. The ground is sometimes so wet that it would be quite impossible to work without more effective means of keeping the water out than pumping it out. Compressed air provides the remedy. A wall or "bulkhead" is erected behind the shield to form a chamber in which the work can go on, and this is kept supplied with air at a pressure of about two atmospheres—sufficient to keep the water from coming past the shield.



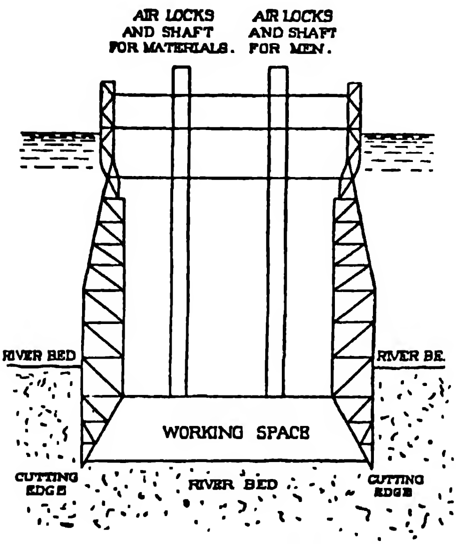
Section through the Earth showing the Greathead Shield ready to be driven ahead
A, Timber piles. B, Hydraulic rams. C, Cutting edge of shield. D, Completed segments of tube.

rapid sequence of blows delivered at the rate of a thousand a minute. This type of tool can be put to all sorts of applications—punching holes in boiler-plates, riveting, caulking, hammering, chipping, and chiselling. Probably you have seen—and heard—the powerful pneumatic chisels used for breaking up the concrete in the roadway. As it is quite easy to convert a to and fro motion into a rotary motion, there are also pneumatic drills and other revolving cutting tools. Such tools are used very largely in mining and quarrying and in driving tunnels through hard rock.

This brings us to another very important use of compressed air, its power to hold back the water that would otherwise enter and flood tunnels bored through waterlogged ground. The London tube railways were built with

a device called the Greathead shield, which is a very strong circular steel wall having a ring-shaped cutting edge.

Similar in principle is the caisson [1] which enables engineers to build or repair the underwater foundations of bridges and piers. The caisson is really a very simple contrivance. In essentials, it consists of a large and very strong steel cylinder, closed at the top but open at the bottom. The caisson is lowered through the water, open end downwards, until it rests on the bed of the sea, or the river. It does not fill with water because air is forced in at sufficient pressure to hold the water back. The upper end of the caisson has a door which opens into a chamber built above it, called the air-lock, from which a shaft leads to the outer air. By way of this shaft men and materials pass into or out of the caisson. Before the caisson can be entered the air in the air-lock must be brought up to the pressure inside the caisson. The men enter the air-lock and the outer door is closed. The air-lock is gradually filled with compressed air until the pressure is the same as that in the working chamber —the caisson proper. Then the inner door can be opened



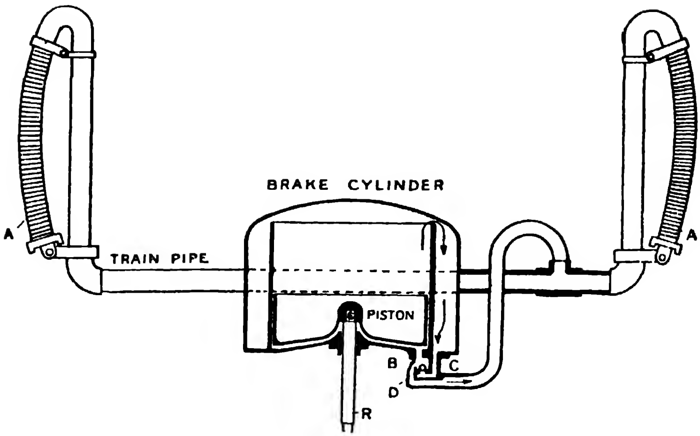
Simple diagram showing the parts of a Caisson

[1] From French *caisse*, a box or chest.

for the men to pass through. If they are going out instead of in, they wait in the air-lock while the air pressure is slowly brought down to the normal atmosphere. I need not tell you that the pressure in the caisson depends entirely on how deep it is below the level of the water. Water is 773 times heavier than air, and 33 feet of water requires an extra fifteen pounds of air pressure to balance it. So a caisson worker—or a diver—at a depth of 100 feet has to be supplied with air compressed to about four times its normal pressure.

In helping to build tunnels and bridges, air is put to a rather special kind of work that is quite hidden from the view of ordinary people. I want to show you the air made to work in places where you can see its power and usefulness for yourself. So we will go to the railway station and watch the trains being brought to a standstill. The power that stops the trains is only air, and what is more wonderful still, air of the same pressure as that we are breathing. All passenger trains, and many goods trains that travel at express speeds, are fitted with "continuous" brakes, which means that the brakes are applied simultaneously to all the wheels. Two systems are in use, the Automatic Vacuum brake and the Westinghouse brake. The vacuum brake is the more commonly used on English lines, and it is in this system that the weight of the atmosphere alone is made to apply the brake-blocks to the wheels.

Under each of the coaches there are cylinders in which pistons move that have their rods connected to the brake-levers. All the cylinders are connected with the engine by a continuous pipe, and it is through this pipe that the action of the brake cylinders is controlled. The brakes are held off by creating a vacuum in the cylinders until the air pressure on top of the pistons is only about 5 lb. to the



" Vacuum " Railway Brake shown partly in Section

An apparatus similar to the above is fitted underneath each railway carriage. The train pipe is made continuous by coupling the flexible parts AA to the corresponding parts on the adjacent carriages. To release the brakes the driver turns on the ejector, and the air in each brake cylinder is sucked out of both sides of piston by the passages B and C The air from the upper side lifts the little ball D on its way out. When the train is to be stopped, air is admitted to the train pipe It then rushes under the piston, but it cannot get into the space above, for the ball closes the passage. So the pressure of the atmosphere forces the piston, and the rod R which is connected to the brake blocks on the wheels, upwards, and the brakes are applied.

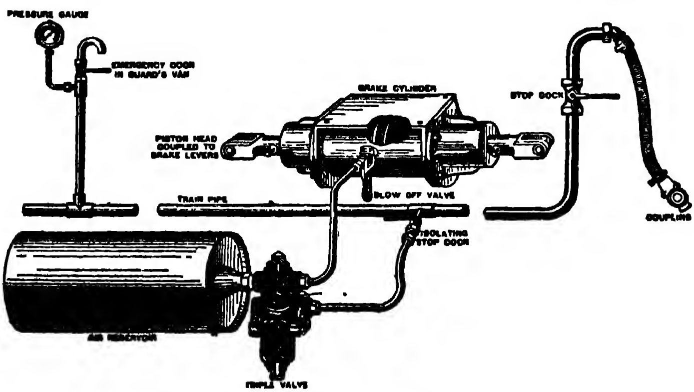
square inch. This is done by a most ingenious device on the engine, called an ejector, in which a current of steam, passing through a cone-shaped jet at great velocity, sucks the air out of the continuous pipe and the brake cylinders. There are two ejectors on the engine—a large one to exhaust the pipe and cylinders quickly, so as to release the brakes after the train has been stopped, and a small one which works continuously to hold them off.

To apply the brake, the driver admits air to the train pipe. It rushes into the cylinders and pushes the pistons up, and so pulls the brake blocks to the wheels with a force of ten pounds to the square inch, that being the difference

between the pressure on the upper or vacuum side of the piston and on the lower or atmospheric side.

The Westinghouse brake acts on the reverse of this principle. The brake-blocks are applied to the wheels, not when the air pressure in the continuous train pipe is *increased*, but when it is *reduced*. The brake levers are moved by a piston working in a cylinder, the piston deriving its power from air under pressure. A pump on the engine compresses the air in the continuous pipe and brake cylinders throughout the train, and so long as this pressure is maintained the brakes are kept off. They are instantly applied by letting the air escape from the train pipe either purposely —as when the driver or the guard wants to stop the train— or accidentally, as when a coupling breaks and the air rushes out of the severed train pipe.

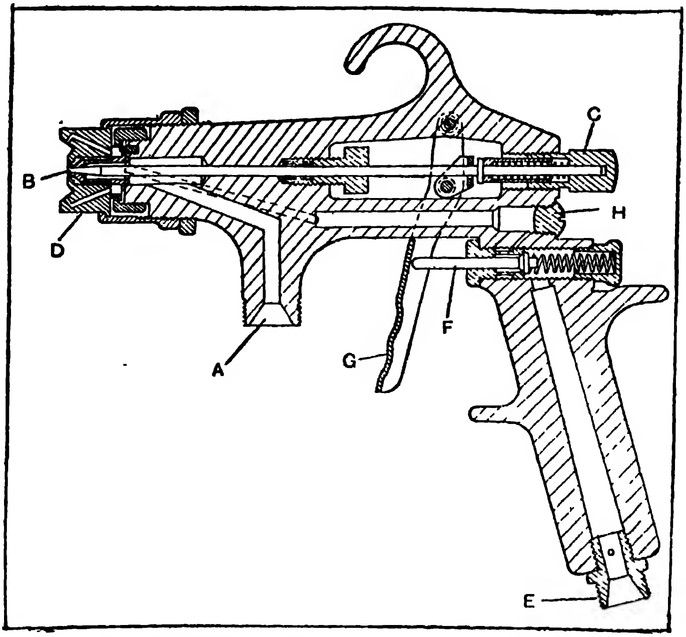
There is an air reservoir on the engine, into which the pump compresses the air. When the engine is coupled to the train, the compressed air from this reservoir flows into the train pipe and fills an auxiliary reservoir and a controlling device, called the triple valve, on each vehicle. Thus the



The Arrangement of a Westinghouse Brake

continuous pipe, the triple valves, and the auxiliary reservoirs are all charged with compressed air, but there is no compressed air in the brake cylinders so long as the brake is not in operation. To apply the brakes the driver opens a valve which permits some of the air to escape from the train pipe. Whenever that reduction of pressure in the pipe takes place, it causes the pistons of all the triple valves to move and permits a portion of the compressed air stored in the auxiliary reservoirs to enter the brake cylinders. This air forces the pistons forward, pressing the brake blocks against the wheels by means of the gear connected to the piston-rods. The brakes are taken off again when the driver admits compressed air from his reservoir to increase the pressure in the train pipe. This returns the pistons of all the triple valves to their original positions. In this position the valves allow the air in the brake cylinders to escape, so that the brake-blocks are relieved of pressure.

In such ways as these science puts air to work. I have only been able to show typical examples out of hundreds. We might have looked at a lady's scent spray, in which a tiny puff of air from a rubber bulb breaks up a drop of scent into a fine rain composed of myriads of droplets; or at the scent spray's big brother, the spraying machine used for painting motor-cars and railway carriages and even houses. And we have only looked at one side of the air-pump's piston—the compression side. What about the other side—the suction side? In pumping air—or any other fluid—we merely take it from one place and push it into another place, a closed vessel of some sort. But if we make our pumps work backwards, to draw the air out of a closed vessel and deliver it over to the atmosphere again, we have an air-exhauster, that will continue to pull the air out of a vessel until there is none left, or next to none. That



A Spray Gun used for Painting. It is shown in section so that the separate parts may be seen

The paint inlet A is connected by a coupling nut either to a one-pint or one-quart suction feed container or to a length of fluid hose joining the gun to a large separate container The paint is led to the nozzle of the gun and the amount is regulated by the taper pointed needle B adjusted by the thrust screw C. As the paint emerges from the nozzle it is atomized by the compressed air which flows through holes in the air cap D This air cap is provided with a central orifice and two subsidiary " spreader " jets to flatten the spray and thus enable a wide surface to be covered at each stroke of the gun.

The compressed air enters the inlet E and passes through the valve F controlled by the trigger G. From this point it passes through holes in the body and thence to the air cap. The trigger G controls both air and paint valves. The first pull on the trigger opens the air valve and further movement withdraws the paint needle from its seating in the nozzle. The reference H indicates the air valve cleaning screw. Reproduced by courtesy of Messrs. The Aerograph Co Ltd.

most useful aid to home cleanliness, the vacuum cleaner, has either a little rotary pump, or a fan in a closed chamber, to create a suction that will draw in the dust and fluff, and even pieces of paper and pins. The air-pump used for

creating a vacuum in such things as electric-light bulbs and wireless valves, or in the tenpenny-halfpenny vacuum flask, is not greatly different in its essentials from one invented nearly 300 years ago by Otto von Guericke, a German scientist, whose fellow-townsmen thought he was a magician in league with the devil.

CHAPTER XIII

The Science of Sound

I expect you know the answer to the profound question: "What noise annoys an oyster?" The answer is: "Any noise annoys an oyster, but a noisy noise annoys an oyster most." The point of the answer is that it enables you to make an odd noise which sounds very unlike speech, although you are speaking quite ordinary words. You need not worry about the oyster. He does not mind noise in the least. He cannot hear it. To any creature that is unable to hear it, noise does not exist.

When we were talking about light I showed you that we do not see light. It is not a "thing", but a form of energy which is reflected from the objects around us on to the retina of the eye, and there stimulates certain nerves to give us the sensation of sight. Sound is another kind of energy of which we become aware when it reaches the nerves of our ears. But it is not by any means of the same kind as the many manifestations of *radiant energy* which can pass across boundless spaces where no air is. In order that the metal wire in an electric bulb shall not burn to a whiff of gas as soon as it becomes heated by the electric current, the bulb is carefully exhausted of air, for we know that there

can be no burning without oxygen. But if we set an electric bell ringing in a vessel from which the air has been withdrawn, no sound will come to us, however violently we ring.

Still, we know that an electric bell produces sound, unless it is in a vacuum; so we can say that air is necessary to the passing on of the energy put into ringing the bell (or at least some part of the energy) so that it is transmitted to the nerves of our ears. We can safely say that, since air is the only medium in which we can live; but it is not strictly true, as a number of experiments would very soon prove. If we set our bell ringing in a vessel filled with a very light gas, hydrogen, say, we should hear it, but very faintly; while if we filled the vessel with a very dense gas, like carbonic acid, the bell would ring much louder than it does in air. We should find by experiment that all fluids, whether gases or liquids, transmitted sound, and all solid substances as well; but we should find great differences in the amount or loudness of sound coming to us, and great differences in the speed at which the sound travelled.

Sound is the effect of a particular kind of energy which stimulates the nerves by which we hear. This energy takes the form of impulses delivered by moving molecules of air; dealing gentle blows, as when we whisper, rougher blows, as when we clap our hands. Even the loudest kinds of noises are produced by an astonishingly small exchange of energy. A distinguished scientist, whose business it is to study noises, has pointed out that the " speech power " of a crowd of a hundred thousand people all talking at once and as loudly as they could, would only provide enough energy, if converted into heat, to make a single cup of tea. And what is it that sets the air particles in motion, so that they can rain those blows upon our ears? It is the property of matter called *elasticity*.

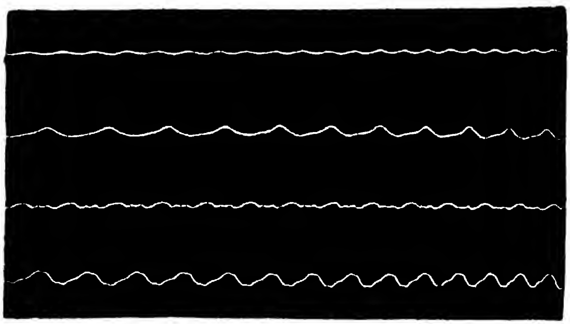
What do we mean by that? A power to stretch like a piece of elastic, perhaps? Yes, certainly a power to stretch, but also an equally important power to rebound. The elastic is ready to spring back as soon as the stretching force is removed. The same thing happens when we *compress* an elastic body; the pressure we apply makes the molecules in the body crowd together in the direction of the pressure. But as soon as the force is removed, back they come to their original position.

Without this property of elasticity there would be no sounds. Whenever matter is strained some motion of the molecules takes place. This motion is passed on to the very elastic air, and the air in turn passes it on and gives us a box on the ears. Now, most substances are elastic, the molecules rebounding whenever they are strained. That is what we mean when we say they *vibrate*. A vibration is a swinging movement in the particles of anything; they move in *one* direction whenever energy is applied to strain them, and in the *opposite* direction by virtue of their elasticity, as when a spring is compressed and then allowed to fly back.

We may put it this way. Sound is produced whenever the particles in a substance are moved to make them vibrate in such degree and at such a rate that the air can pass on enough of the energy to stimulate the nerves with which we hear. You will agree that it is not very complicated. What *is* complicated is the exact form of the air-impulses which bring us different kinds of sounds, though later on we must try to understand something about them. The forms of these air-impulses set going by the spring-like vibrations imparted to substances are really very important, for they are the foundation of speech and of music. The niceness or nastiness of sounds is due to them. So they have been very carefully studied. The science which deals

with them is called harmonics, and the rhythmic, to and fro movements of the particles in a vibrating substance are known as *harmonic motion*.

We all know that sounds vary in *pitch*—they are high or low, squeaky or groany. The pitch depends on the rate of vibrations of the particles in the substance making a sound; that is, the number of complete to and fro movements that



The Vibrations of a plucked String

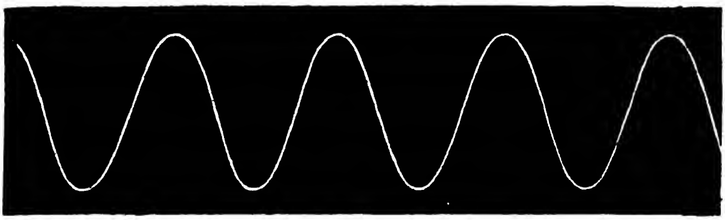
The top one was plucked in the middle, the second one third of the way along, and the other two still nearer the end. It will be seen that the quality of the tone depends on the form of vibration. The more complicated the form the "brighter" the note sounds.

take place in a given time. Low notes are produced by long, slow vibrations, and high notes by short rapid ones. Our ears cannot detect the pitch of sounds made by vibrations occurring less frequently than eight a second, nor more frequently than 40,000 a second.[1] When we listen to a gramophone and hear the pitch of the notes beginning to fall, we know that it is running down. Then we hastily wind the handle, which restores the normal speed to the turntable and the normal pitch of the music. Or we may let it run right down, to hear the strange sounds as the

[1] The range of *musical* notes, i.e. those caused by *regular vibrations* that are pleasant to hear, is not nearly so great as this.

music gets slower and slower and the pitch falls to a deep bass groan.

A note of any pitch is always produced by the same number of vibrations, whatever the material that is vibrating. It is on this fact that the musical scale is based, as those readers will know who are learning music. They will know that what is called the *natural diatonic scale* consists of seven sounds, of which the note of lowest pitch is called the fundamental note, and the eighth note the octave. Now,



Trace produced on smoked paper by the vibrating prong of a tuning-fork drawn steadily across it

there is a definite relationship between any two notes and the number of times per second that a body vibrates in order to make them. Whether the body is a vibrating string, as in piano or violin, or a vibrating column of air as in a flute or an organ pipe, if 400 vibrations give a certain note, then 500 give the third above this note (as from C to E, or D to F), 600 vibrations give the fifth (as from C to G, A to E), and 800 the octave. When the piano tuner comes, he brings with him a tuning-fork, the steel arms of which always vibrate at the same rate and consequently produce a sound of fixed pitch. He tightens the piano string which makes this note until it vibrates at exactly the same rate as the tuning-fork, and he then has a standard by which he can correctly fix the pitch of all the other notes.

Now, let us go back a little way. We have seen that the

pitch of a sound is determined by the frequency of the vibrations set up in things. There is another quality of sounds that we have yet to consider. They vary in degrees of loudness and softness. You can ring the dinner gong gently, or so as to make a frightful row; the difference in the intensity of the sounds produced by the same material is clearly a matter of the energy you spend in setting up the vibrations. But that is not all. The area across which the molecules vibrate also affects the loudness of the sound. A big gong makes more noise than a little one. A violin string stretched between two nails on the wall would make a very thin, feeble sound, but the sound of the same string vibrating in unison with the thin wood forming the back and belly of a violin is loud enough to reach all parts of a large hall. The sounding board of a musical instrument increases the intensity of sound by increasing the vibrating surface.[1]

Now that we have found out a little about how sounds originate, and about their pitch and loudness, we can better understand how they travel and how we come to hear them. How fast do sounds travel? Do they all go at the same rate, do you think, or do some kinds race ahead while others lag behind? We have only to listen to a band playing at a little distance to be quite clear about that. We can recognize the tune—proof positive that all the sounds from all the instruments are coming across to us at the same speed. If they were not, what we heard would be a jumble of mixed noises, not a tune. We are therefore quite sure that all sounds travel at the same speed. But we must qualify this by adding—if they are travelling in the same medium. Sounds go faster in liquids than in air, and faster

[1] A page or two back I said that the intensity of the sound also depended upon the density of the medium in which it was made. So if you beat the gong on a mountain top, where the air is thin, the noise would astonish you, not by its loudness but by its feebleness. It would not sound a bit like itself.

still in solids. Perhaps you have performed the telephone post experiment, which always greatly surprises those who try it for the first time. Choose a still day, and get a friend to tap one telephone pole while you stand beside the next pole. The tap should be just loud enough to be audible. Now put your ear to the pole and ask your friend to tap again. This is what you hear: TAP—tap. The first sound is the louder, and it comes by the posts and the copper wires. The little air-borne sound is a laggard. As it is sometimes useful to know the speeds of sounds in different substances, I will set out the more important so that you can easily look them up when you want them:

In air the speed of sound is 1120 feet per second.[1]
In water the speed of sound is 4780 feet per second.
In copper the speed of sound is 11,666 feet per second.
In iron the speed of sound is 16,822 feet per second.

And so we come to consider how the impulses given to substances to make them vibrate become part of our consciousness, a part of daily experience that it would be so terrible to do without. Just think what it means: voices, music, bird-song, or the hum of insects—even mechanical noises help to make us happy, simply because they are familiar friends. All sounds make pictures in our minds, mostly pleasant ones. The noise of a train or a car, the click of a ball against a cricket bat, the rustle of leaves, or the sound of footsteps—such things and thousands like them help to make our memories, sensations, and emotions. Yet they are only waves in the air, delivering tiny impulses to the drums of our ears.

I would like to help you to understand the very peculiar

[1] This is at ordinary temperatures. Sound goes faster in hot air than in cold, the speed at 0° C. being 1090 feet a second. Two feet a second can be added for every degree Centigrade.

nature of these air waves. We dropped stones into a pond, to make waves, some time ago (in Chapter VI), and we have it clearly fixed in our minds (I hope) what is meant by the terms *wave-length* and *frequency*. Let us go back to the pond again, because there are one or two things it will help to make clear. Suppose we visit the pond on a still day, when no wind is blowing. We will amuse ourselves by dropping on the water a few leaves or bits of paper. Now let us make some waves; quite little ones will do. We will drop a pebble in the pond and watch the ring of ripples spread outwards to the bank. Now observe the floats we threw in. They move up and down on the wavelets, but they do not change their relative positions. The *wave-motion* travels to the bank, but the floating objects do not move any nearer. The wave-motion lifts them up and down, but it does not carry them along. Or take a piece of rope and give it a sharp shake. A wave travels along the rope, but no fibre in it really moves forward. A knot tied in it remains at exactly the same distance from either end.

A wave is produced when the particles of a vibrating substance begin to move, one after the other, at regular intervals. This is the *harmonic motion* I mentioned on p. 169. Perhaps you are puzzled to understand how it is that waves move forward while the water—or other substance—stays where it is. "How," you ask, "can you talk about the speed of a thing if it doesn't move?" Well, the wave-*motion* goes forward, particle by particle. When you hear a noise, the noise does not make the air move forward like a gust of wind. If a gun is fired on a still day it will be heard with equal loudness by any number of people at the same distance from the gun; east, west, north, or south—it doesn't matter in what direction they are, for the sound travels in all directions. But what about the smoke? That does not

travel at all; it stays in a slowly dispersing cloud over the gun. When we say a sound is " borne on the air ", we do not really mean that. We are indulging in poetic licence. If the sound was really borne the smoke of a gun would be borne too.[1]

I hope you have not forgotten what I told you about harmonic motion; or how the molecules of an elastic substance rebound after they have moved forward under strain. Suppose such a molecule moved forward in the air under the impulse of the vibration of the table-top when you tap it. Imagine it as a dot in the middle of a long row of other dots. The first dot moves, the next moves a *little after the first*, the next a little after that, and so on. There will be a compression as the dots come together, for all the dots in front of the dot that moved first are at rest, and possessed of the *inertia* of the garden-roller; they are reluctant to move. The elasticity of the dots makes them rebound, however, so that they move apart again, relatively to each other, and thus the compression is followed by a rarefaction. The first state is denser than the normal, the second is less dense. The sketch on page 175 shows how the state of greatest compression forms the crest of a wave, and the rebound or the state of rarefaction, the trough.

Let us exchange our dots for air-particles and see if we can now picture how our waves of compression and rarefaction are able to travel *in all directions*. There is a skylark above our heads; the energy of his song disturbs all the air particles at an *equal distance*. He is therefore the centre of a sphere of sound waves, and every particle in the sphere is vibrating—that is, it is first pushing up against the particles in front and then " easing up ". But how, you may

[1] This takes no account of air-currents or wind, which affect sound-waves in various ways.

wonder, is the wave-motion imparted to the air a long way ahead of the original sphere? How does it travel? Or to put it another way, why does not the wave resume the normal air-surface after the first surge and rebound? Remember the strange property inertia, which makes matter reluctant to change the direction of its motion. Hard to move is also hard to stop moving. The sphere caused by

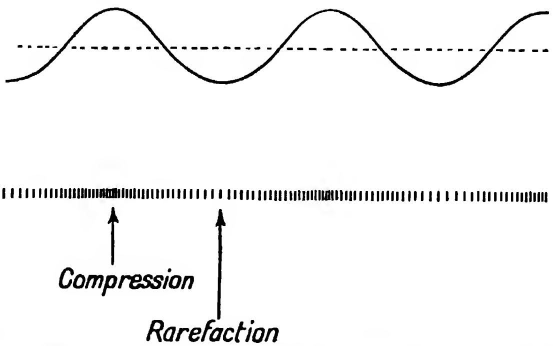
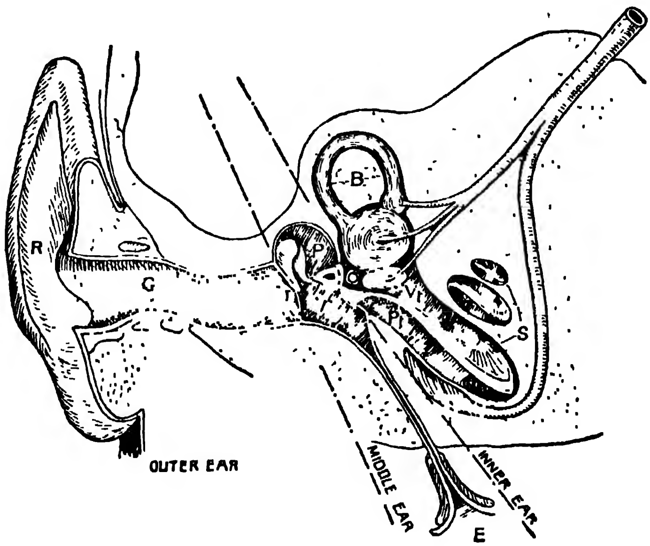


Diagram showing how the state of greatest compression forms the crest of a wave and the rebound or the state of rarefaction the trough

the first disturbance of the lark's song was a sphere of compression—air molecules jostled against unwilling molecules; as they recoil, they form a sphere of rarefaction. But inertia makes them carry on a little too long this time; and so, instead of the sphere of rarefaction returning the air surface around the skylark to the normal, it *enlarges* the surface. This makes another sphere of compression, and so the process goes on again and again, forming sphere after sphere. You can see how the wave-motion comes in, if you think of any part of the sphere as the front of a wave travelling in a straight line.

These spheres within spheres, these regions of air denser than the normal followed at regular intervals by regions less dense than the normal, are still not sound, however.

They are only the *transmitters* of sound. To produce sound there must be not only a transmitter but a receiver. The receiver is a piece of mechanism more marvellous than any ever produced in a factory. In all the organs of our amazing bodies, nothing is more amazing than the ear.



Diagrammatic Section through the Right Ear

R, pinna, G, auditory meatus, T, tympanum; P, chain of bones (hammer, anvil, and stirrup); O, oval window; S, cochlea; Vt, scala vestibuli, Pt, scala tympani, B, semicircular canals; E, eustachian tube; *r*, round window.

Yet, unless we have earache, few of us think about our ears from one year's end to another. As a matter of fact, the ear is so complicated a structure and so important to health and efficiency, that many doctors spend their lives in the study and treatment of ears alone, but none of them would claim to have mastered the subject.

The external ear is simply an attachment for gathering sound. When man was newer to the business of being a

man, he was able to twitch his external ears backwards and forwards to collect sound, but he has long since lost that faculty. From the external ear, a canal runs to the " middle ear ", the wall of the middle ear being what we usually mean when we speak of the drum. This is identically the same in principle as the bandsman's drum, being a thin membrane tightly stretched. Its Latin name is *tympanum.* Behind it, in the middle ear, are three tiny bones called, from their shapes, the hammer, anvil, and stirrup (*malleus*, *incus*, and *stapes*). These little bones are jointed together, the hammer head receiving vibrations from the drum when a sound wave strikes it, and passing them on to the anvil, which in turn sets the stirrup vibrating. The little chamber of the middle ear is filled with air, and does actually perform a tiny breathing process, using up the oxygen and disposing of the carbonic acid gas. But since, as we know, there is the air-tight wall of the tympanum between the middle ear and the external ear, the middle ear gets its air through a tube communicating with the nose, the Eustachian Tube. So all good nose-breathers supply their middle ears with warmed and filtered air.

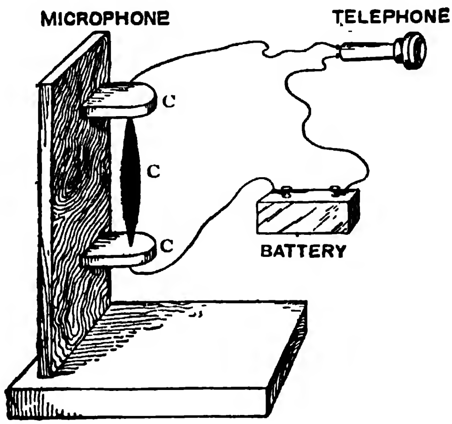
The stirrup passes its vibrations through a fluid-filled chamber of the *inner* ear and into a spiral passage called the cochlea, whence they return to a little membrane " window " which receives the vibrations but does not pass them on. This is where the sound waves stop. But the business of hearing is not yet finished. From the cochlea nerves pass to the brain, carrying the heard message. I want you particularly to notice the structure of the cochlea because it is so very wonderful. The cochlea is a spiral tube contrived with a double passage. The vibrations pass up one passage to the head of the spiral and down the other passage to the little window already mentioned.

Within the cochlea is a structure known as the Organ of Corti. I do not know who Corti was, nor if the name was given to signify a physical organ or a musical one, but the structure of the Organ of Corti is almost exactly like the mechanism of a keyboard. It is a very complicated arrangement of microscopic parallel fibres stretched across a spiral staircase in the cochlea, which gradually gets narrower and narrower, so that the fibres are all of different lengths. They are in contact with corresponding hair-cells—about 15,000 in each ear. These are cells immediately connected with the " hearing-nerve " leading to the brain, and they are provided at their free ends with short, stiff hairs, which seem to act somewhat like the hammers which strike the strings of a piano. But it is not correct to suppose that the Organ of Corti actually transmits sound-waves. It possibly converts the vibrations reaching the drum into electric vibrations, in a manner you can better understand when you have learnt about electricity.

I need not remind you how important a place the science of sound occupies in modern life. Wonderful instruments for sound production and reproduction confront us wherever we go. Telephones, gramophones, wireless, the " Talkies " —those are some of the most exciting. And we cannot go far without hearing the electric horn of a motor-car, in which the very rapid vibration of a small metal plate, or diaphragm, makes a great deal of noise. Modern science is not only concerned with repeating and transmitting sounds; it also seeks to control them. Doctors have found that noise is very bad for people's nerves, and that it damages our power to work well. Scientists have worked out a scale by which different kinds of sounds are very accurately measured. The degrees of loudness are calculated in *decibels*, zero being the point at which a sound is just perceptible

to the ear. Even a garden on a still day has a "sound value" of 20 decibels, while a single pneumatic drill has an intensity of 90 decibels.

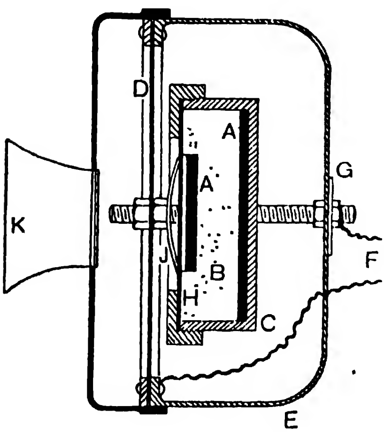
As science has come to the conclusion that we make a great deal too much noise, inventors are at work to make things quieter, for most noises can be reduced, and sometimes done away with altogether. Buildings are now so designed that they may be as nearly sound proof as possible. The walls and floors are insulated with materials in which the vibrations cannot travel. An ordinary room carries on a sound, by echo after echo, for several seconds after the original sound has ceased. The best way of getting rid of echoes is to line the buildings with an absorbent material that will "soak up" the vibrations like a sponge. A kind of seaweed called eel-grass is one of the best things yet discovered for this purpose, and large quantities are gathered on the shores of Nova Scotia, to make linings for buildings all over the world.



C, C, C, Carbon
A simple form of microphone

Most inventors have worked to make sounds louder, not softer; they want them to travel farther instead of seeking ways of absorbing them. Sounds are magnified by a device called a microphone (Greek, *micros*, small, *phone*, sound). It makes the faintest sounds audible. It enables us to listen to the tread of a fly or the fall of a feather. This wonderful

instrument is used in the telephone transmitter to control the conversion of the energy of sound waves into electrical energy. It was invented by Professor D. E. Hughes, an English scientist of great distinction, in 1878. In its simplest form, the microphone is a little pencil of a kind of charcoal that is a bad conductor of electricity. Yet it has the very strange property of becoming a good conductor, when it is made to vibrate. We can explain this roughly by saying that the variations of pressure set up by vibrations in the molecules of this particular form of carbon produce corresponding variations in conducting power, and consequently in the strength of an electric current that is able to pass through it.



Sectional Diagram of a Microphone

K, Mouthpiece. D, Metal diaphragm J, Spring-washer. A, A, Carbon discs. B, Fine carbon granules. H, Mica diaphragm. C, Brass capsule. E, Outer case (metal or bakelite). G, Insulating washer (if metal case). F, Connexions which carry current to telephone receiver. In broadcasting a solid marble block is used as an outer case in order to keep out extraneous sounds.

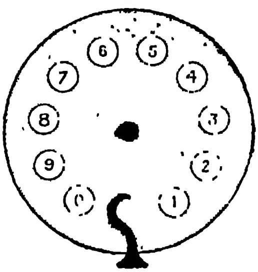
The carbon pencil is loosely supported upright between two blocks of carbon connected in a battery circuit. It acts as an automatic switch for the current, keeping it shut off until it is vibrated. The carbon is so sensitive to changes of pressure that the least sound wave sets up vibrations in the molecules, which permit the current to flow in exact proportion to the intensity of the vibrations. All the fluctuations of the sound impulses are changed into electrical impulses, which are changed again to sound impulses by a receiver placed in the electric circuit. The telephone is not nearly

as complicated as it looks. The carbon pencil has given place to a little box filled with fine grains of carbon, and it is into this that we speak when we use the telephone. In front of the carbon " granules " there is a thin metal disc or *diaphragm* which vibrates in accordance with the sound waves that reach it. The vibrations make the carbon granules cling together, or " cohere " in greater or less degree. The more they cling together, to that extent is their electrical resistance lessened, and they thus permit the passage of a fluctuating current in the receiver in the circuit.

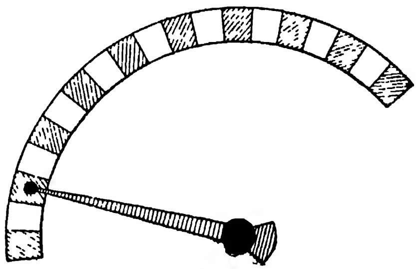
As in the telephone transmitter so also in the receiver. A thin iron diaphragm vibrates again, this time under the influence of the changing electric current. The diaphragm is placed close to (but not actually touching) a little electro-magnet, in which the changes of magnetism are controlled by the changes of the current permitted to pass by the carbon granules of the transmitter. The electro-magnet vibrates the diaphragm in the receiver exactly in sympathy with the voice-vibrations imparted to the first diaphragm. A larger diaphragm and a more powerful electro-magnet make the wireless loudspeaker.

But though, in principle, the telephone is an easy thing to understand, its practical application to the needs of modern society involves complications to turn our hair grey! One of the greatest marvels of scientific achievement is the automatic telephone exchange, wherein the girl operators are superseded by an electric " selector ". You are probably familiar with the public end of this marvel. You know the dial on the base of your instrument, by means of which you make your own connexion; anyone you like, out of thousands. The dial consists of a circular plate having numbered holes, and a " stop ". If you put your finger in one of the holes, the plate turns quite easily as

far as the stop. All telephone numbers, for the purposes of the dial, are assumed to contain four figures; that is to say, if you wish to connect with number 246 you must dial 0246. We will suppose that you are calling the number 3465. You put your finger in the hole marked 3 and turn the dial. This movement sets up an electrical impulse, which travels to the exchange and there enters a little instrument called a selector. The selector itself has a semicircular dial and pointer and the shaded sections of the dial represent numbers and are actually contacts with the



The Dial



The Selector

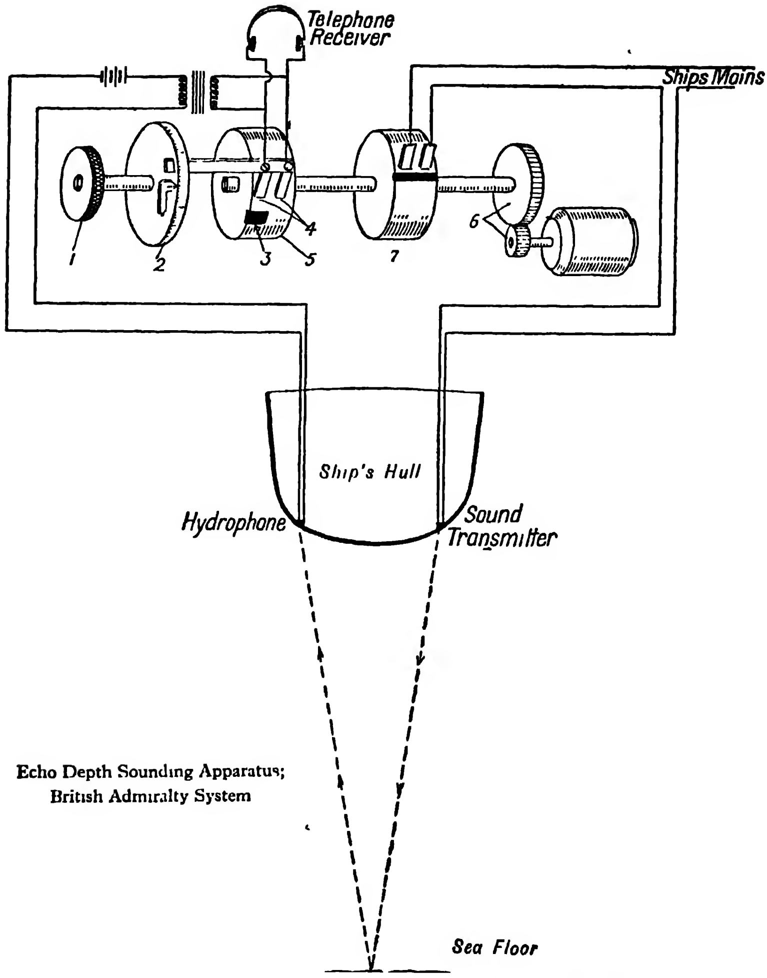
electric circuits connecting with the selector controlling the 3000 group of telephones. By moving the disc to 3 on your dial you connect with a selector in the exchange which finds the number 3000. Similarly, when you dial the 4, your selector at the exchange finds the 400 group of telephones. The tens and units are arranged in ten rows of ten, one above the other, so when you dial 6 your selector rises up six rows, to what we may call the sixty storey. Last comes the 5; the selector moves along five places to the right and your connexion is made. But here is another marvel, out of hundreds to be found in the automatic exchange. Before you begin dialling your number, you must lift your telephone off its hook. That action automatically finds for you a selector that is free to attend to you.

The vibrating diaphragm that transmits the sound-waves in the telephone and loudspeaker comes before us again in the gramophone. In this case, however, it is independent of electric current, since it is not necessary to convey the sound impulses over a long distance.[1] Gramophone records are made by an electric recorder in which a microphone changes the sound impulses of voice or music into electrical impulses and transmits them to a diaphragm connected with a little arm carrying a needle. The needle travels in a spiral groove cut in a rotating disc of soft wax. It makes tiny indentations in the side of the groove in exact accordance with the fluctuations of the sound waves.

The master record thus made would not be of any use for playing on a gramophone. The wave imprint in the soft wax would be very quickly destroyed. This imprint is transferred to the gramophone record with which everyone is familiar by a process called electrotyping. The original wax disc is put in a bath of salts of copper through which an electric current passes. The current decomposes the water so that the atoms of hydrogen and oxygen are set free as gas, while the copper is deposited on the wax as a perfectly fitting coat of metal. From the metal mould thus formed, our records are pressed in a soft material that afterwards hardens. When a record is played on the gramophone, the needle reproduces the vibrations recorded by the indentations in the grooves, and transfers them to the diaphragm of the sound box. Then they set up sound waves of the same frequencies as those originally recorded.

Let us close this chapter with a few words about sound wave reflections or echoes. Perhaps you think echoes don't matter very much; they may startle or amuse us, but they

[1] In the kind of gramophone with electric "pick-up" the vibrations set up by the record are first converted into electrical energy and then turned into sound-waves. This is explained in Chapter XVIII.



Echo Depth Sounding Apparatus;
British Admiralty System

The hydrophone consists of a simple microphone enclosed in a rubber body. 5 and 7 are brass discs rotated on a shaft Each has an ebonite strip shown in black. When the ebonite comes under the brushes bearing on 7 the circuit in the mains is broken and a hammer strikes the diaphragm in the transmitter. Disc 5 short-circuits the telephone, except once in each revolution when strip 3 comes under one of the brushes 4. No sound is heard in the telephone except when 3 comes under the brush at the instant when the sound is produced, or at the instant when the echo reaches the hydrophone. The telephone brushes are adjusted by a knob 1 carrying a disc 2, graduated with a depth scale which reads at the pointer. The shaft revolves at three revolutions per second, so that 1 degree displacement of the telephone brushes corresponds to rather less than 1/1000 sec. or rather less than 2½ ft. in depth.

are not really important. Well, if you had to design a public building such as a theatre or lecture hall or assembly room, you would very soon discover that sound reflection is an extremely troublesome thing to deal with. I can only think of one set of people who are grateful for echoes—the seafaring folk. To them, sound reflection is very important indeed, for it is a means of telling them when their ships are in danger of striking rocks or sandbanks.

Up to the time of the Great War, seamen had no means of finding out what depth of water they were in except by sounding with a lead-line. Nowadays, however, most ships are fitted with an echo-sounding apparatus called a *hydrophone*. On the side of the ship there is a transmitter, a device for making sounds, underwater, of a definite frequency. On the other side of the ship there is a receiver. The transmitter sends out the sound waves, and the sensitive microphone in the receiver picks up the echo coming back from the bottom of the sea, or a rock, or a sunken vessel. On the ship's bridge the two instruments are connected in a recorder. This apparatus measures the time interval between the sound impulses and the echo and gives the answer in depth of water. The hydrophone is a very valuable gift of science to the cause of safety at sea.

CHAPTER XIV

Beginnings of Electricity

If you were asked to name some of the famous Englishmen of the time of Queen Elizabeth, I am sure that you would have no difficulty in making out a list. There would be the great adventurers, Hawkins, Drake and Raleigh, and the

great poets Spenser and Shakespeare. You might remember Francis Bacon and probably other famous men of that golden age of English history. Yet of one famous man of that time our history books do not tell us much. His name was William Gilbert, and he was the Queen's physician. When she died, he was appointed physician to her successor, King James the First.

In Italy, the great Galileo was upsetting all sorts of apple-carts by his discoveries, and getting himself into very hot water; in England at the same time William Gilbert was preparing the foundations on which later generations were to erect the vast structure of electricity. He was very much interested in the voyages of adventure and discovery made by the Elizabethan seamen; still more, he was interested in the tales he was told of the strange behaviour of the mariner's compass; how it " dipped " as ships sailed to low latitudes, and deviated from the true north. At that time people were not sure whether the magnetic needle was attracted to the Pole Star or to an island of loadstone in the Arctic Ocean, so huge and powerful that it drew the nails and bolts from ships that approached too near, so that they fell to pieces. By observation and experiment Gilbert showed that the behaviour of the compass could be explained only on the theory that the earth itself was a magnet.

Another thing that interested this doctor to Queen Elizabeth was the strange way in which certain substances had power when rubbed to attract small objects. It had been known for thousands of years that amber had this power, but Dr. Gilbert found that other things had it as well. He invented what we should now call an electroscope, an instrument for detecting small charges of electricity. It was only a little metal needle pivoted on its centre, but it moved when a piece of amber or jet, glass or resin that had

been excited by rubbing with silk or fur was brought near to it. He also invented the word, now such a common one in our speech, by which this strange power of attraction might be known. He called it *electricitas*, because *elektron* was the Greek name for amber.

When Dr. Gilbert died, other men of inquiring minds took to experimenting with electricity. They made simple machines by which the rubbing could be done better than by hand, and in course of time they made machines powerful enough to produce sparks. A person standing on an insulated stool could be charged with electricity by having his body briskly rubbed or beaten with fur, and then sparks could be drawn from him.

When we speak of a thing as " insulated " we mean that it will not permit the passage of electricity. The word comes from the Latin *insula*, an island, so it really means to cut off the flow of electricity, as an island is cut off from the mainland by the surrounding sea. Dr. Gilbert had found that there were not many substances that he could electrify by rubbing. He found that there were far fewer *electrics* than *non-electrics*, as he called the things that could not be electrified. (We do not now speak of " non-electrics ", but of *insulators* or non-conductors.) However hard he rubbed a metal rod, nothing happened—as he thought. Really, just as much happened as when he rubbed a rod of glass or sealing-wax or any other of his " electrics ", only the electricity leaked away to the earth and could not be made to do tricks. It was not until long after his time that the difference between electrical conductors and " insulators " or non-conductors was understood. It is quite easy to electrify a metal rod, or even a boy, if you give the one a glass handle and the other a glass stool to prevent the electricity escaping at once to the earth. In fact, you can

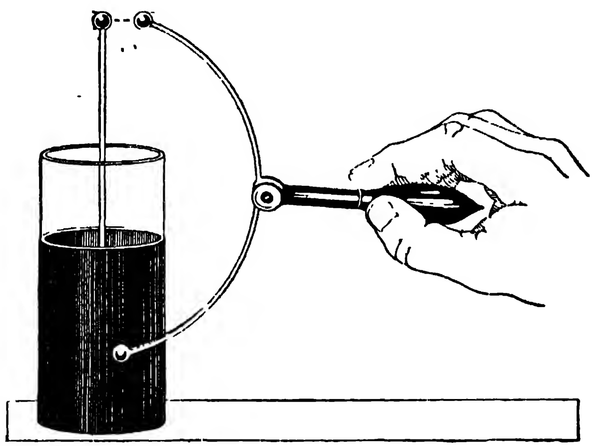
electrify anything by rubbing, if you take suitable precautions against leakage, though the substances old Gilbert called " electrics " are quite the most amusing in the way they show off their electricity.

If you had been Dr. Gilbert, puzzling your head to account for the very strange properties of magnetism and electricity, you would very soon have discovered certain likenesses and certain differences—" clues " to their nature that you would have been quick to follow up. For instance, once you have made a magnet, let us say by stroking a thin steel bar with another magnet, or with a piece of the natural magnetic iron called magnetite or " loadstone ", the magnetism will remain in your magnet for a long time. The magnet thus made you can use to make more magnets, for magnetism is led from one piece of iron into another—*induced*, as we say.

In short, magnetism stays where we put it, at all events for a time. Very different in this respect is the behaviour of electricity, which won't stay put. In all the rubbing experiments we make, we find that the electricity rushes away in an instant, and the flow or current we induce is far too fleeting to be of any use. Though we have changed some of our own heat energy into another kind of energy, all we have got for our trouble is a tiny spark, or a little pith ball or scrap of paper moved an inch or so.

Nearly a hundred and fifty years passed after the death of Dr. Gilbert and the next great electrical discovery. This was that electricity can be stored, and it was made at Leyden University in Holland by a student who wished he hadn't. The student (his name was Cuneus) was working with a peppery old professor who thought it would be interesting to electrify some water. The professor led the electricity from his rubbing machine into a jar of water, by way of an

iron chain. The iron chain was a good conductor, the glass jar a good insulator, and the professor continued to lead electricity into the water until Cuneus accidentally touched the chain and let all the electricity out again—through his body. That annoyed them both, for Cuneus received a severe electric shock and dropped the jar, and the professor was very peppery indeed.



Leyden Jar

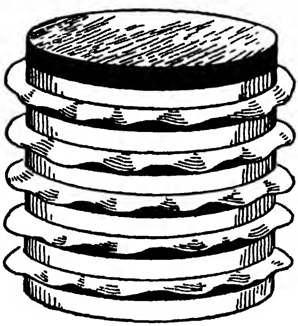
This jar charged with electricity produces a bright spark when discharged

Out of that remarkable discovery that electricity can be " bottled up " came the Leyden jar, a very simple receptacle or " condenser " in which electricity can be stored.

A Leyden jar is a glass jar coated for part of the way up, both inside and outside, with tinfoil. A brass rod connected with the tinfoil lining leads out of the mouth of the jar. The tinfoil *inside* the jar takes the place of the water in the jar Cuneus dropped; and when this conductor is charged, the outer tinfoil covering also becomes charged. If you hold the jar and touch the brass rod you receive a shock,

but if you use an insulated rod to connect the inner and outer conductors, the stored electrical energy escapes in a spark.

Now, it was a great advance to be able to store electricity, even in the trivial amounts those eighteenth-century electricians were able to make. But it did not help them very much, for they still knew no way of taming the force they experimented with. Though they had driven a wild horse into an enclosure, they were quite unable to harness it, and as soon as the gate was opened, out it went like a streak. But about forty years after Cuneus had his shock, a great Italian scientist showed how electricity might be tamed. He was Alessandro Volta, whose name we commemorate every time we use the word volt, which is the unit of electrical pressure. He was, so far as we know, the first man to make an electric current, a stream of electricity flowing in an appointed course, like water in a pipe, that could be turned on and off at will. Volta discovered that when two different metals, in contact, are chemically attacked by a weak solution of acid and water, one of the metals is decomposed and a steady flow of electricity passes from one to the other through the acidulated water.[1] He made a pile of discs of copper and zinc, each " couple " of discs, one of zinc and one of copper in contact with each other, being separated from the next couple by a piece of cloth dipped in acidulated water. When the top and the bottom discs of the pile were connected by a wire, Volta found that the wire became heated, and that there was a steady flow of electricity from the copper to the zinc

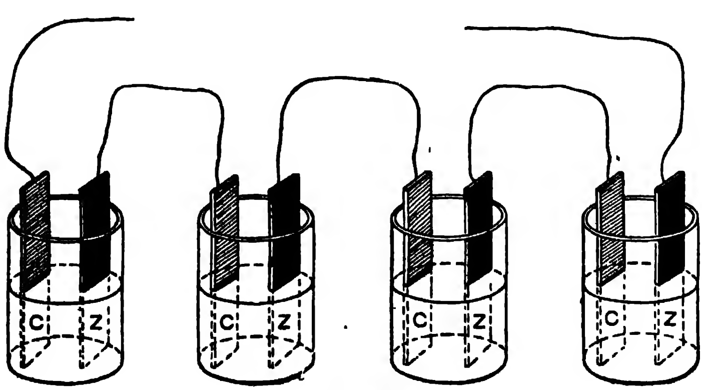


Volta's pile

[1] Water containing an acid is a much better conductor than pure water.

until the zinc was all used up. Volta's Pile was the forerunner of all the electric batteries that have ever been made since.

And now, having produced an electric current instead of the instantaneous discharges of Dr. Gilbert's " electrics ", we may begin to ask ourselves, " What *is* an electric current?" As a start towards finding an answer we may observe the ways in which magnetism and electricity differ and the ways in which they are alike. We have already noticed one very striking difference, the permanence of magnetism and the fleeting nature of electricity. There are several others. We can electrify almost everything, in some degree, but there are very few substances that show the property of magnetism; only the metals iron and steel, nickel and cobalt, and their alloys. Again, the force of a magnet seems to be concentrated in its ends; every magnet has a north-seeking end or " pole " and a south-seeking pole, but the metal lying between the poles has no attractive force. Electric force does not behave like this. Instead of being concentrated in a particular part of a conductor electricity *flows* to other parts, so giving us our electric current.



Electric Battery
C, Carbon in acidulated water. Z, Zinc

And now we may look at the ways in which electricity and magnetism resemble each other. The most important resemblance is that both exhibit what we may call a twofold nature. The ends of a magnet are opposite in character, or " directive ". Any magnetized bar of iron, if it is free to move on an axis, like a compass needle, will arrange itself with its ends pointing north and south, and I am sure you know that the same end of a swinging magnet always points in the same direction. And no matter how many pieces you may cut your magnet into, every little bit becomes a new magnet, with north-seeking and south-seeking poles. You can never have a magnet with only *one* pole. If we bring the ends of two pivoted magnets close to each other a strange thing happens. The north pole of one repels the north pole of the other; they move apart from each other, and the south poles behave in the same way too. But if we present a north pole to a south pole they attract one another.

Now, any electrified body also behaves in this way. It either attracts another electrified body or repels it. The early experimenters soon made that discovery. It seemed that there must be two sorts of electricity, and that the sort they got by rubbing a stick of glass with silk was not the same as the sort they got if they rubbed a stick of amber with wool. For though both the glass and the amber either attracted *or* repelled a third electrified body, whichever the glass did, then the amber did the opposite. They found that, as in the case of the poles of the magnet, like repelled like, while unlike attracted unlike. And they soon made another discovery, one I have already mentioned. They found that one electrified body can induce electricity in another body, just as a magnet can induce magnetism in a bar of unmagnetized iron. They found, too—and this is very important in our understanding of electricity—that

electrified bodies *attract* unelectrified bodies until they have charged them with their own electricity, when they repel them.

All this sounds very complicated. Lots of people say to themselves: " Dear me! This is much too mysterious for *me* to understand!" I want you to look round for a moment at the very obvious ways in which this mysterious thing, electric energy, comes into your life. There are electric batteries, direct descendants of Volta's Pile, almost within a hand-reach, I expect; one in a pocket torch, two in the wireless set, another to work the bells. There is an electric-light switch at your elbow and a telephone within reach. There are cars, lorries, buses—each with its device for making millions of electric sparks. The trams are not far away, nor the electric trains, and you can hardly take a walk without sight of the pylons with their cables. So somebody must understand electricity!

Perhaps you would like to know what electricity *does*, without worrying about what it *is*. Well, I don't think anyone will quarrel with that, for I do not think anyone can tell you what it is. I do not think anyone can tell you what anything is, really and truly—at bottom. Bread and butter, say; or toffee or tin; we can tell you the names agreed upon for the bits of stuff they are made of, and how the bits come together, or fall apart, how their relationships to each other and to everything else are governed by those laws of chemistry and physics that we glanced at, at the beginning of the book. The electrical laws likewise explain the *relationships* of electrified and unelectrified bodies, and we cannot hope to know how electricity works, unless we take the trouble to study the facts about these relationships. To all of which you make reply: " Perhaps! But it is very complicated!"

But there you make a mistake. The rules of electrical energy are not nearly as hard to understand as people think they are. Only, we must start at the beginning if we are ever going to understand them clearly. I tell you this, because I want you to see that a few chapters in a book like this are not going to make an electrician of you. The mysteries in this science can only be unravelled one by one; you must go ahead from clue to clue, making certain that you know their significance. There is no other way out of the woods than the paths the pioneers trod for us, Gilbert and Volta and many another, and it is for this reason that the first steps in electricity are so important.

So let us go back to p. 192 and then make a real effort to get the hang of this repulsion and attraction business. We can get at the main facts if we imagine some experiments with some glass rods and pieces of silk. Let us suppose that we have three rods and three pieces of silk, and that we electrify them by rubbing each rod with a separate piece of silk. This is what we shall find:

1. A glass rod always repels another glass rod, and a piece of silk always repels another piece of silk. ("Like repels like.")

2. A glass rod and a piece of silk attract one another. ("Unlike attracts unlike.")

3. A glass rod or a piece of silk attracts any other body with which it has not been in contact. But if a third body is brought in contact with the glass or the silk, that body gains the power to attract or repel, as the case may be, in proportion as the glass or silk loses the power.

We cannot get any electricity out of anything without doing work. Here is another of the "exchanges of energy" which have come into chapter after chapter of this book.

We can get it (in recognizable force) by stroking the cat or brushing our hair, by rubbing non-conductors like glass and silk, by burning up zinc in a battery, by moving a magnet in a coil of wire, by heating certain metals, and so on. And no doubt you have noticed that two parts are always necessary to the making of electricity. I have called them " bodies ", because that is usual, but you can call them what you like—materials, substances, or just " collections of atoms ". One collection of atoms called glass, another collection called silk (and a collection in your own hand, of course, but you cannot perceive the electricity in that because it leaks away so quickly). Those are the bodies or collections of atoms in our rubbing experiments. In other ways of electricity-making there are zinc and copper, magnet and wire-coil, &c. I hope you see that there is no electricity until the atoms are stimulated or excited to produce this remarkable form of energy. And you cannot excite one body without making use of another body.

Alessandro Volta

Here is the glass attracting the piece of silk with which we rubbed it. It is quite clear that there is energy here. There is a state of tension, a stretching or straining between these two bodies just as if they were being drawn together by some visible substance like a stretched elastic. They are drawn together because when we excited the glass and the silk the atoms of glass *took something away* from the atoms of the silk, and it is this something belonging to the silk but removed to a distance by the glass that attracts the

silk so strangely. We may think, in fact, that the "something" is struggling to get back to the silk!

This something is a particle of electricity. It is called an *electron*, and I am going to tell you more about it in the next chapter. Although it is almost infinitely small (forming, indeed, only a tiny part of an atom—and we know how small *that* is), the electron is of immense importance in modern science, for it is the source from which come all forms of radiant energy. These particles of electrical substance—for substance of a sort it must be—since the particles have size and weight—are always the same, whatever kind of atom they belong to. And every atom has electrons, as we shall see in the next chapter.

What I want you to try to see now is that atoms that have lost electrons are in a particular electrical state, different from the electrical state of atoms that have gained electrons. Thus, in the glass and silk rubbing, the glass by taking some of the electrons belonging to the silk has acquired a different electrical state; so has the silk, because it has lost some of its electrons. For, in the ordinary way, the electricity in both the silk and the glass is "lying doggo"; it is neutral, being perfectly balanced between the electrons and the matter composing the remainder of the atoms. It is, in fact, the difference in the electrical *states* of two bodies that we really mean when we speak of electric discharge or electric current. By rubbing silk and glass we jerked some of the electrons out of the silk atoms and these electrons were "captured" and retained for a little while by the glass atoms. The disturbance of the ordinary neutral state of the electrons produced an "energy-squirt" such as we tried to picture when we dealt with light.

These two unequal states are electric forces. We might call one A and the other B, or one glass-electricity and the

other silk-electricity, but we don't. You know that we call them " positive " and " negative " electricity. Perhaps you are puzzled to know which is which. There should be no difficulty about this, however, if you remember that if the charge is positive in one body, then the charge in the second body must be negative. There is really no reason why one charge should be called positive more than the other. The two charges exactly balance one another; in other words, the quantity of electricity in the one charged body is equal to the quantity in the other body. The thing to remember is that there can be no electric " energy-squirt " until something has happened to drive an electron out of an atom to put it in a different state from the surrounding atoms.

But, in science, it is necessary that every word or symbol we use should have a perfectly definite meaning, so it was agreed that the electron should be called a particle of *negative* electricity. Positive electricity is that which remains in an atom when an electron has been taken away from it. When an atom loses an electron it is said to be positively charged; while an atom that gains an electron has a negative charge, for it has acquired an extra particle of negative electricity. In a current flowing along a wire there is believed to be a constant movement of electrons, passing on from molecule to molecule, atom to atom.

I said, a few lines back, that the *quantity* of electricity in the one body exactly balanced the quantity in the other body. This brings us to another thing about electricity that often puzzles people. What exactly do we mean when we speak of a " quantity " of electricity? We all know that several measurements are used in electricity, and we understand something of the importance of such terms as volt, ampere, and ohm in their everyday application. Yet quantities—of anything—are really quite simple; they are only

the *measurable relationships* of things. Ask yourself what you mean by weight, for example. (If you cannot decide at once, turn to page 36, Chapter III.) Or let us examine the quantities observable in a tumbler of water. There is the volume of a given portion of water—the space it occupies; there is the weight of this given portion, and as we know how these quantities are proportional to each other we can define the *density* of the water as the ratio of the weight to the volume. Such as these are the sorts of relationships we need to consider when we want to measure or compare ordinary things; and in a similar manner the electrical measurements explain the relationships of the two electric forces, positive and negative.

The first " measurable quantity " of electricity is based on an inverse square law of attraction and repulsion of electrified bodies, which is exactly the same as the law of gravitation. The attraction falls off as the inverse square of the distance between the two charges.[1] The attractive or repulsive force thus becomes a strength of electric charge that we can now think of as a means of measuring a "quantity of electricity". When we say that the quantity of electricity in one charged body is twice that of another, it is understood that we mean that it exerts twice the force on a third body at the same distance from both the charged bodies. This charge or force or quantity of electricity depends on proportions that can only be explained mathematically, but we can look at it as the *amount* of energy that can be set to do work. But as soon as we start to use the energy, by passing it along a conductor as an electric *current*, the positive and negative charges take on another relationship, for the larger the charge on a body the greater is the

[1] *Inverse square*; this means that if the distance between two bodies is doubled, the power of attraction is only one-fourth as great, at three times the distance, the attraction is one-ninth, and so on.

electric *pressure* in it. There can be no current without the two charged bodies—one with a surplus of electrons, the other with a deficiency of electrons. The pressure is the result of the strain or " tension " of these unequal states in the electric balance of the atoms in the two bodies. The electrical flow is always from the body at the higher pressure or " potential ", as it is called, just as a stream of water is always at a higher pressure than all the water below it, until it reaches sea-level, though the *amount* of water at the higher level may be a great deal less than the amount of water at a lower level. For measuring the difference of potential between the positive and negative charges in an electric current, electricians take the pressure of the electricities in the earth. As these completely neutralize each other, the earth pressure is 0, which is a very convenient " level " to start measuring from, either up or down. Actually, only the positive flow is measured, for if the pressure of positive electricity is high in a body, then the negative is low, and vice versa. All that really matters is the difference of potential, for this is the measure of electrical energy, or *electro-motive force*. The unit of measurement is the volt, after the great Volta.

But what about the other unit of current measurement, the ampere? We know that a current is spoken of as so many amperes at so many volts.[1] The easiest way to understand this is to liken the current to a flow of water. If we wanted to know how much work we could get out of a flow of water in a pipe, it would not be enough to know what was the pressure of the water—the height it came from; we should also need to know how much water came through the pipe in a given time. We measure this as its

[1] More often we multiply the amperes by the volts and express the product as so many *watts*. Ten amperes at 50 volts, or 5 amperes at 100 volts, both transmit a power equal to 500 watts. A kilowatt is 1000 watts.

rate of flow, so many gallons a minute. Well, we want to know exactly the same thing about electrical flow, for on that depends its power to do work. We want to know *its rate of flow*. To express water power we use an equation in which we have pressure multiplied by gallons multiplied by minutes and electric power is expressed in a similar way. Volts are the equivalent of pressure, and amperes[1] the equivalent of gallons; and the volts multiplied by the amperes multiplied by the time of flow give the measure of electric power. To conduct a given amount of power along an electric wire, we can send a large rate of flow at a low pressure, using a thick wire like a large-bore pipe, or we can send a small rate of flow at a high pressure, using a thinner wire; just as in the case of water-power we could get the same power by using more pressure and a smaller pipe.

A dull chapter, you think? Maybe, but turn your mind to the electric servants waiting upon your wants. The wonders of everyday electricity stand firmly on these " dull " laws of quantities and proportions.

CHAPTER XV

Radium and Radiation

I dare say some readers have made gas-mantle " photographs ". All that is necessary is a photographic plate, a piece of silver paper, some black or brown paper, and an old gas mantle. The plate is wrapped in the black paper (in the dark, of course), and a figure or device cut out of the silver paper is pasted on the outside of the wrapper. The

[1] Named in honour of André Marie Ampère, a famous French mathematician and scientist, born 1775, died, 1836 As the ampere is rather a large unit, the amount of electric flow in a conductor is often measured in thousandth parts of an ampere, called milliamperes.

bits of the broken gas-mantle are spread over this, and the whole is then wrapped up and stored away in a dark cupboard for two or three weeks. When, at the end of that time, the plate is developed, it is found to show a faint and ghostly image of the tinfoil figure. On top of that are very clear impressions of the bits of gas-mantle.

The gas-mantle has taken its own photograph; and as the plate has been completely protected from visible light, the picture must have been made by invisible light. Moreover, as neither brown paper nor tinfoil can affect a photographic plate, the invisible light must have come from some substance contained in the mantle. This substance is a compound of the rare metal thorium.[1] It is one of the small class of metals called "radio-active" because they possess the extraordinary property of sending out, under ordinary conditions, a stream of radiant-energy. Evidently this energy must possess some of the characteristics of ordinary light, since it affects a photographic plate. We know that our eyes are insensitive to all but a small proportion of the wave-lengths of the energy we speak of as light. Is it possible that the atoms of thorium give out light of their own accord? And if so, how do they do it?

You may have wondered why a chapter on radium comes to be sandwiched between chapters on electricity. When, with a sigh of relief, perhaps, you reached the end of the last chapter, you may have thought: "What! Nothing about dynamos and motors? No mention of X-rays or wireless?" And then, on turning on a bit, you discovered that those applications of electro-magnetism had not really been omitted. But why this sandwiched chapter on radium?

[1] Gas-mantles are made of cotton-fabric dipped in a solution of nitrate of thorium and a very small proportion of another rare metal, *cerium*. As soon as the gas is lit the cotton burns away, leaving behind a sort of skeleton of the oxides of thorium and cerium, which give an intense light when heated.

The answer is: That it helps us to understand electricity. I tried to show you in the last chapter that electricity is energy bound up in the atoms of matter. The positive and negative forces we examined a few pages back are due to a most mysterious balance or adjustment of the bits of " stuff " of which atoms are made. The way in which the balance acts to send out squirts of energy is so very marvellous and so important to us that we cannot ignore it just because it is rather hard to understand.

Let us go back a bit. We know that all things are made by combinations of atoms of the ninety different elements. We regard the atoms, in fact, as the bricks with which the world is built, and I told you (in Chapter IV) that we could never find a speck or grain of matter simpler than an atom; which was true—as far as it went. But this speck of matter is by no means the simple thing we left behind in Chapter IV. The atoms are like very delicate springs. We may still think of them as bricks, but no longer as *solid* bricks. For the moment we may imagine a patent kind of " spring-brick ", and believe that, whenever the bricks are jerked in a particular way, the springs give out a pulse of energy.

The atoms of the element thorium have springs that are infinitely more powerful than the atoms of the other elements, except the heaviest element of all, which is uranium. A French scientist, Professor Henri Becquerel, proved in 1895 that, like thorium, uranium and its compounds give off some kind of rays capable of acting on photographic plates. Soon afterwards a much more important discovery was made; it was found that these rays have electrical effects. When a body charged with electricity is moving between the poles of a magnet, it is drawn out of the straight course, moving more towards one pole than the other, according to whether it is charged with positive or negative

electricity. The rays given off by uranium and the other "radio-active" substances behaved towards a magnet as if they were electrically charged bodies.

The study of these strange rays [1] was carried on by the famous scientists, Madame Curie and her husband. They soon discovered that the atom of uranium was constantly breaking up or "disintegrating", and that by this process there was formed an entirely new atom, which they called radium, because it was very active in giving out radiation. These wonderful discoveries, which were made in the closing years of last century, showed that certain of the very heavy elements are actually undergoing a transformation into entirely different elements. Atom by atom they become torn to pieces, and no human power can stop or hinder the process. Yet—and this is perhaps the most astonishing of all the miracles of science—what happens to the minute particles in which these dramatic changes take place can be watched. You don't need to be told that they are invisible; any atom is millions of times too small to be seen. Still, they can be watched, measured and calculated, photographed even. More, the energy set free as these atoms rend themselves in pieces is made use of in the effort to cure one of the most terrible diseases afflicting humanity, the disease called cancer.

Anyone who possesses a luminous watch can see one stage of the changes radium undergoes. The hands of the watch are coated with a paint containing tiny crystals of a compound of zinc, and an incredibly small quantity of radium. A close examination with a magnifying-glass shows that the luminous "glow" is really due to a number of minute flashes of light. In fact, the radium atoms are ex-

[1] They were called rays because they had the property of penetrating substances opaque to light.

ploding, and as they explode they throw off particles, little bullets which make a splash of light when they hit a crystal. These bullets are called *alpha-particles*, and we shall look at them more closely. Before we do so, I will tell you a little about the general properties of radium.

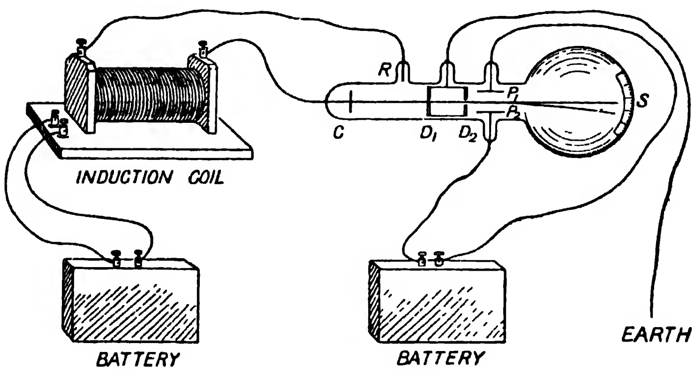
I have already said that it is formed by the breaking down of the atoms of the element uranium, which is found in many kinds of ores. One kind of ore is called pitchblende, a little of which occurs in Cornwall. Another ore is called carnotite. Whatever the ore, it never contains more than a very small proportion of radium, some hundreds of tons being needed to yield a single grain.[1] Pure radium is a metal, but it is always prepared as a compound. Such enormous quantities of ore have to be handled, and the treatment is so complicated and expensive that radium is far and away the most precious metal in the world. It costs about £12 for a thousandth part of a gramme, and several hundred pounds' worth are needed for the treatment of even a slight case of cancer.

No element on our earth is so strange as this. You know that its compounds are luminous in the dark. It not only gives out light, but heat as well, for it is always a little warmer than surrounding objects. Besides the bullet-like alpha-particles shot out by radium, there is another kind of projectile, as well as a very penetrating kind of ray. And you must know that while the radium atom is shooting out these three different sorts of rays it is changing into an entirely new atom. This is not a metal, but a very strange gas, luminous, and like radium able to give out rays. This new substance is called radium emanation,[2] and it is as

[1] The richest ores only contain a very little uranium; and there is a definite ratio of uranium to radium, which shows that there cannot be more than 1 part of radium in every 3,000,000 parts of uranium.

[2] Latin, *emanare*, to flow out.

extraordinary as radium itself. By intense cold it has been condensed to a liquid and frozen to a solid which glows in the dark. Radium emanation has but a short life. As it shoots out rays it gives rise to a new element, which is



Discovery of the Electron

The negative particle of electricity, which has been christened the electron, was discovered by Sir J. J. Thomson, and was measured by the apparatus depicted in the diagram.

A battery is connected to the induction coil which sends the discharge through the special tube which Sir J. J Thomson made. Another battery supplied an electric field between the plates P_1 and P_2. The electrons set out from the cathode C and become a narrow beam in passing through a hole in D_1 and D_2. This stream of electrons then passes between the electrified plates and also between the poles of a large electro-magnet which is not shown in the diagram. The screens D_1 and D_2 are earthed so that they will not become charged. The electrons are repelled by the negative plate and will be attracted by the positive plate so that the beam will be bent out of its normal path, and as it strikes a phosphorescent screen S at the end of the tube the amount of displacement may be observed.

called Radium A. Radium A changes to Radium B, Radium B to Radium C, and so on, change succeeding change through a long period until at length there appears an element without the power to change or send out rays. This stable element is one we all know. It is lead.

Let us look now at the three kinds of radiation which accompany the break-up of the radium atom. They are

named after the first three letters of the Greek alphabet. Here they are:

Alpha (α) particles,
Beta (β) particles,
Gamma (γ) rays.

The alpha-particles and the beta-particles are the bullets I have spoken of. The discovery of their true nature is an achievement of the present century, the reward of exploration into the remotest fastnesses of matter carried out by great scientists of our own time, like Lord Rutherford and Sir J. J. Thomson. There is nothing in science more wonderful than these discoveries, which have revealed to us the marvellous structure of atoms and the manner in which they provide us with radiant energy.

The alpha-particles shot out by the exploding radium atoms were proved to be specks of matter with a positive electric charge. Methods were devised for catching or trapping them so that they might be examined. They were allowed to pass through the walls of a very thin glass vessel. The terrific speed with which the particles travelled—some 10,000 miles a second—carried them easily through the thin glass, but once inside they could not get out again. Then a very astonishing discovery was made. The alpha-particles were found to be atoms of the gas helium.[1] Helium is one of the rare gases of the atmosphere, like neon and argon. Like neon, it is used for illuminated signs, but its chief use is to provide the lifting power for airships.[2]

The alpha-particles are positively charged. It was therefore supposed that after having fired off an alpha-particle the radium atom must be left with an unwanted negative

[1] More strictly speaking, the alpha-particles are the *nuclei* of helium atoms. See p. 209.

[2] Helium has one great advantage over hydrogen for that purpose; though it is four times as heavy as hydrogen, and much less easily procured, it cannot catch fire.

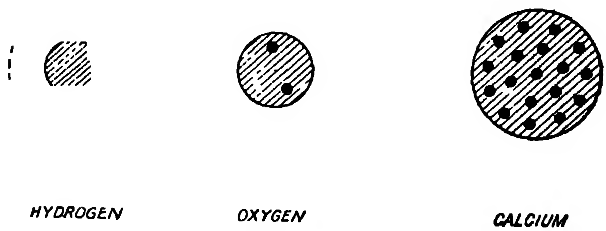
charge. Consequently it was no surprise to find that the atom next shot out a bullet which carried a negative charge. This is the beta-particle, which is simply a very swift electron, or particle of pure negative electricity. It only weighs about 1/8000 as much as the alpha-particle, but it travels with many times the speed. The third kind of radiation shot out, the gamma-ray, is quite different from the other two. It is not a particle at all, and so has no electric charge, but is a pulse of intensely powerful radiant energy, having the properties of X-rays, but much more penetrating. We may regard it as the flash of light which accompanies every explosion of the self-firing radium gun.

Very wonderful instruments have been invented for the study of alpha-particles. It was soon realized that these minute projectiles might be used as spies to find out what atoms are like inside. Lord Rutherford set to work to explore the insides of atoms by bombarding them with alpha-particles. We noticed how the particles make a splash of light when they strike the crystals in the paint used in a luminous watch. Now, a moving body is always turned aside by collision with another body; so if the particles are first made to pass through a thin metal foil, and then brought to rest by a prepared screen on which the impact is revealed as a flash, it is possible to calculate the speed and mass of a particle by the amount by which it is turned from the straight course by a collision with an atom of the metal foil.

This experiment led to another very remarkable discovery. Most of the alpha-particles pass *right through* the atoms of the metal foil, through hundreds and thousands of atoms in fact, without being deflected at all. Most of the bullets do not hit anything—simply because *there is nothing to hit!* But a very small proportion of the alpha-particles,

one in ten thousand, perhaps, *do* hit something, for they are turned aside. And the angles by which they are deflected show that they encounter something in the atom very hard and heavy and with a large electric charge.

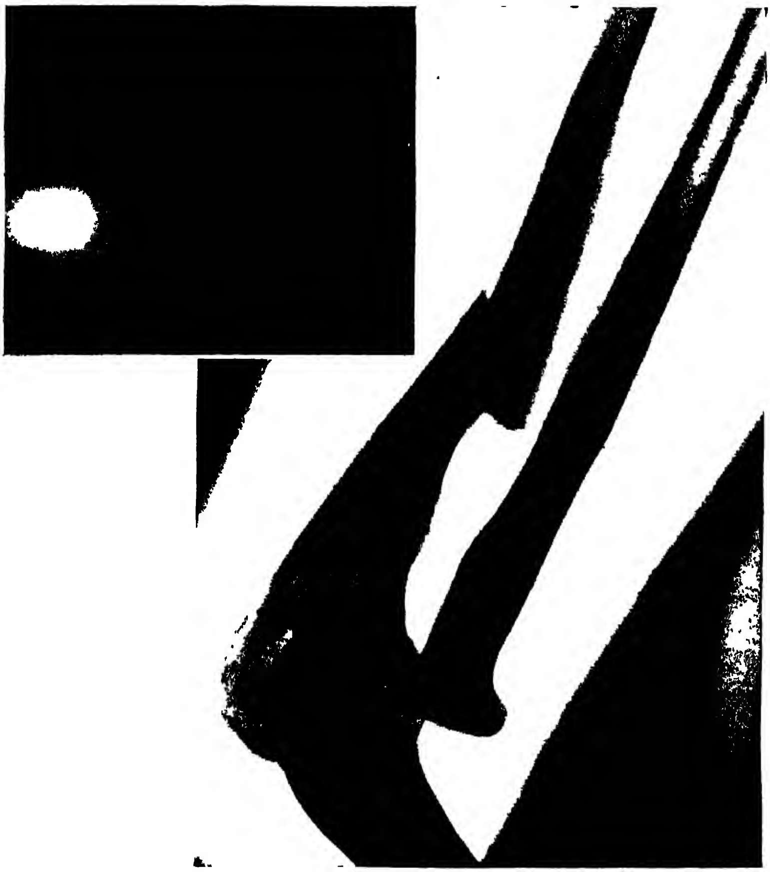
The proportion of hits to misses compels us to readjust all our ideas about atoms, for it makes it clear that atoms are mostly empty space, and far from being the solid particles they were supposed to be! We now know that every atom



A Picture of Atoms

The electrons are represented by black dots, the positive electricity is represented by the shaded spheres

contains this something, very solid and heavy, yet so small that it only occupies a minute fraction of the total bulk of the atom. Of what, then, does the rest of the bulk consist? The answer is that any and every atom is very much like a miniature solar system. The solid, heavy part—the part that knocks the alpha-particles out of their courses—may be likened to the sun; and around it there revolve, at immense speed, a number of much lighter particles, which we may think of as the planets revolving round the sun. These "planets" in the atom are the particles of negative electricity that play such an important part in our lives. They are electrons. The atom, then, is not a minute "brick" of solid matter. It is a tiny solar system, full of electricity.



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X-RAY PHOTOGRAPHS

At the top left-hand corner is shown a radiograph showing the shadow of a lead cross through four inches of mild steel and also a hole (a defect) in the steel. The other photograph shows a fracture of the Ulna, one of the bones in the forearm. See page 214.

The heavy part of an atom—the " sun "—is called its " nucleus ".[1] It carries the positive charge of the atom, and nearly all its weight, but as I have said, it is many thousands of times smaller than the atom. All the nuclei of all the atoms in your body would go comfortably into a teaspoon, yet if they did, the teaspoon would weigh all but a small portion of your total weight. The electrons revolve in paths or " orbits " around the nucleus, at varying distances from it, but always at an immense distance in proportion to their size. Every electron is exactly the same as every other electron, no matter what kind of atom it belongs to. It carries the same negative charge; and every atom has a different number of electrons, and just as many of them as are needed to balance or neutralize the positive charge of the nucleus.

The electrons race round the nucleus millions of times a second, so fast that the outermost electron of all forms the " shell " or boundary of the atom; that is to say, the size of an atom is bounded by the circumference of the outermost orbit occupied by an electron. As I told you in another chapter, an atom is of a smallness that we cannot possibly grasp, in relation to ordinary things. An atomic nucleus is only a few million-millionths of an inch across. But if you think of the nucleus as a golf-ball, then the size of the atom containing it would be about that of a park of half a square mile. The park will have a fence or wall, the atom has none. It has a racing electron tracing its boundary. If a man could run fast enough round a park, you might mistake him for a fence!

And yet these infinitely small specks of electricity give us all the riches and all the energy in the world, for they are the matter of the world. The chemical properties of

[1] Plural, *nuclei*.

the different atoms, their power of combining with one another, depend on the number and arrangement of the electrons they contain. The lightest and simplest atom, that of hydrogen, has a nucleus with a charge which is balanced by a solitary electron. The nucleus of the oxygen atom has a charge eight times as great, so the atom has eight electrons. Each of the elements has a different number of electrons (called its "atomic number"), ranging from hydrogen with one to uranium with 92 times the charge on its nucleus, and 92 electrons.

Science is very much concerned to find out all that can be known about the structure of atoms because atoms are the source of energy—the power to do work. The energy of the atoms depends on the particular arrangement of the electrons in their orbits. There are many ways in which electrons can be separated for a short while from their atoms—shaken out, or jerked out, as it were. We shook some out when we rubbed glass and silk. They are shaken out whenever light falls on them, or heat; by chemical action and by electricity. Indeed, there are so many ways that it is quite impossible to name them all.

But an electron never neglects its job of patrolling its track or orbit in the atom for long. Though it may be jerked or shaken out when its atom is excited, it soon takes up its patrol again. And though it may leave its atom and lead a free existence for a little while, it will soon attach itself to some other atom that has lost an electron.

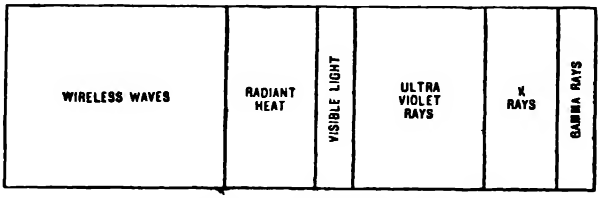
The manner in which atoms absorb and give out energy depends on the movement of electrons from one orbit to another, or from one atom to another. I can only give you here the very crudest idea of what happens, for we are dealing now with a state of things that cannot be explained except by mathematics. You must know, first of all, that

in any atom there are only certain *possible* orbits for the electrons to race round in. An electron cannot trace any course it likes anywhere within the circumference of its atom, but must stick to one or another of a definite number of orbits. Perhaps in the middle of your town there is a church around which you could make a circuit on a bicycle by a choice of roads at different distances. You could make a " circular tour " round the church at a few hundred yards from it, or at half a mile from it, or at a mile, but you could not make a circuit at, say, three-quarters of a mile, because there is no road. The nucleus of the atom is like that church, and the orbits of the electrons like those roads. The electrons themselves are like you on your bicycle. They go round and round, but they can only go where there is a road. Why they are obliged to stick to these particular orbits, though the atom is mostly empty space, is more than I can say. Perhaps, some day, you will be able to find out for yourself.

The important thing to know, however, is that when anything happens to excite atoms, some of their electrons leave their orbits and either pass to further orbits or race off to other atoms in search of new homes. The electrical balance of the atom as a whole (and of the molecule of which it forms a part) is thus upset, and it is said to have absorbed energy. But no orbit ever remains unoccupied for long. Another electron jumps back to fill the vacant orbit and the atom returns to its normal state. In doing this it gives up the absorbed energy in the kind of vibration we know as wave-motion. It is a squirt of radiant energy and we can analyse it very closely by observing its spectrum.

The wave-length of the radiation depends on the amount of energy given out, which is much greater for high-frequencies than for low-frequencies. Here is a diagram

which shows at a glance the wave-lengths of the different degrees of the electromagnetic spectrum. Notice what a very small " band " or section of it gives us visible light. And notice, too, what a very wide band is occupied by the

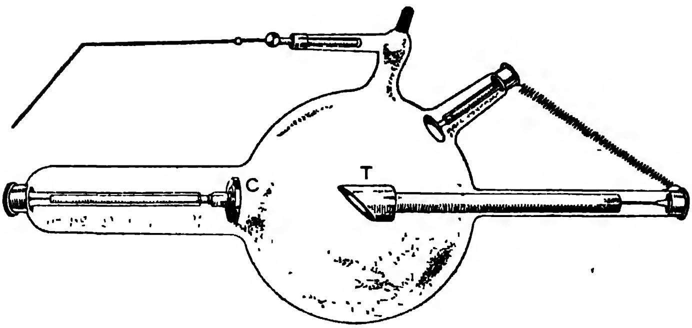


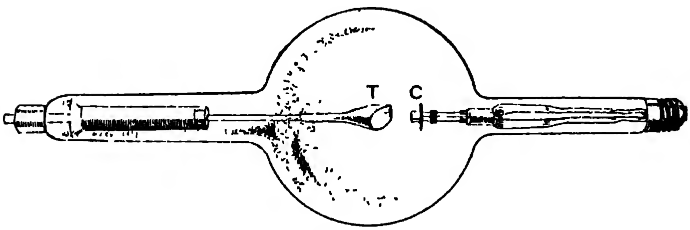
Variety of Radiant Energy Waves
The long waves commence at the left hand and the shortest waves are at the right hand

high-frequency radiation called X-rays. We will close this chapter with a glance at this very useful form of wave-motion.

X-rays are produced when rapidly moving electrons are suddenly stopped by matter. If a sufficiently powerful electric current is passed through a sealed glass tube that has been nearly exhausted of air, a stream of electrons will be created. For in the rarefied air there will be free electrons roaming about, and these will act as conductors. (If the tube was full of air no current would pass, air being a non-conductor; and if it were quite empty no current would pass either, for there would be no electrons.) These free electrons collide with atoms and knock more electrons out, until there are a great many electrons rushing about and hurling themselves at the sides of the tube. Whenever they hit the glass they make X-rays.

It was by passing electricity through vacuum tubes that X-rays were discovered. Indeed, the very existence of electrons became known through experiments with such tubes. The power of the rays to penetrate substances opaque





X-ray Tubes

Gas tube at top and incandescent cathode tube below. C is the cathode and T the tungsten target. The X-rays are produced by firing at a tungsten target in vacuum a stream of electrons from the cathode. It is the sudden stopping of the electrons which produces the X-rays.

to ordinary light was discovered by Professor Röntgen, a German scientist, in 1895. Professor Röntgen noticed that some crystals lying near his vacuum tube were glowing with a strange light. That was very extraordinary, for although the glass walls of these tubes glow brightly under the bombardment by the electrons, in this particular case the tube was covered by black paper. Another thing that Professor Röntgen discovered was that when he placed a solid object between the tube and the crystals the object cast a shadow.

The rays caused by the electron stream are called cathode rays, and the vacuum tube in which they are produced is

a cathode-tube. Cathode is simply the name given to the negative pole or terminal of an electric circuit, the positive pole being called *anode*. These tubes are very much like the long-shaped electric lamps you sometimes see, only there is no filament or wire inside. Two little metal plates are sealed in the tube, one at each end, with metal rods leading outside, so that they can be connected with a high-tension electric current. The cathode is the plate connected with the negative wire, and it is from this that the electrons are shot off. I have told you that the electrons make rays when their flight is stopped by solid matter, like the glass walls of the tube. In the cathode tube used for X-rays, however, a tungsten " target " is placed opposite the cathode, to catch and stop the electrons.

Another kind of tube now much used for producing X-rays works on the principle of the wireless valve. It is called a hot-cathode tube. Instead of using the free electrons in a rarefied gas to carry the current across the tube, the vacuum is made as perfect as possible, and the electrons are " jerked out " of the cathode by heating it to incandescence. The faster the electrons can be made to travel, the shorter is the wave-length and the greater the penetrating power of their energy-squirts when they hit the target. The electron stream can be made to travel faster by increasing the voltage, that is, the difference in potential between the cathode and the anode. With a sufficiently high voltage—several hundred thousand volts—the rays can penetrate five inches of solid steel.[1] The swiftness of the electron stream at very high pressures would shatter glass tubes to pieces, so the tubes for " hard " rays, as those of great penetration are called, are made of metal. Moreover, although the rays have wonderful curative powers in

[1] The much shorter gamma-rays of radium penetrate about three times as far.

many diseases, they can destroy living tissues, and for that reason the tubes are enclosed in protective cases of lead. We owe a great debt of gratitude to the brave men and women who have cheerfully endured terrible suffering in winning knowledge of X-rays and extending their uses. Sad to say, a great many have lost their lives in this splendid work.

At the beginning of the century, X-rays were only a scientific curiosity; their uses are now so diverse that there is hardly an industry that would not be the poorer without them. And I need not remind you how important a part they play in surgery. X-ray photographs can be taken of any object or material. The variations in the density of the material through which the rays pass produce on a photographic plate a picture that is best described as a shadowgraph. This shadowgraph can be seen with the eye if a *fluorescent screen* [1] is used instead of a plate. This screen is prepared with certain chemicals that give out a glow when X-rays fall on them. The parts of the object under examination that are opaque to the rays throw a sharp shadow on the screen.

CHAPTER XVI

Electricity in Harness

A little village in the heart of Sussex recently attained a distinction of which it is very proud. In the rooms of cottages the light was switched on, and in workshops and farm buildings, machines and appliances were moved for the first time by electric power. It was the first village in the south-east of England to " go on the grid ".

[1] Fluorescent, from a Latin word " to flow ". The word is used to describe certain substances that have a curious bluish appearance that suggests water flowing.

You know what the grid is. It is the name given to the network of electric cables by which a supply of power is being carried to every part of the country, the villages and hamlets as well as the towns and cities. In 1926, an Act of Parliament was passed to put into the hands of a body of experts, the Central Electricity Board, the right to erect the steel towers called pylons[1] wherever they were needed to carry the electric cables. Great Britain was divided into several large areas of many thousand square miles, each area having a scheme of its own for making and distributing current in the most economical way. Central Scotland was the first area to put its scheme into operation, and it will not be many years now before the network of the grid is spread over the length and breadth of Britain.

The result will certainly be an enormous increase in the use of electricity. The more we use the cheaper it will become. At present, it is a good deal more expensive than in many other countries. This is mainly because we have been making it in small quantities, except in the very largest towns, and transmitting it at low pressures. Electric current is most cheaply delivered from place to place when it is at the highest possible potential. The grid scheme provides for main transmission cables carrying a voltage of more than 130,000 volts. These will supply a network of cables at a lower voltage, and it is to be hoped that the reproach of dear electricity will soon be a thing of the past.

We are really only just beginning to use electricity. To most of you who are reading it, that statement may be rather surprising, for you were born into an electrical age that was ready-made for you. There has always been so much electric power in your world that you have probably

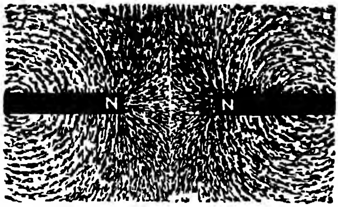
[1] Pylon is the Greek word for gate. Tower-like structures, flanking the gateways of temples, were called pylons, or any tower of geometrical design, standing by itself.

not noticed how the power increased as you grew up. Yet a quiet and unobtrusive servant has been growing up beside you, increasing in strength and usefulness year by year. No more than ten years ago a machine like a steel rolling-mill, that called for 5000 horse-power to drive it, was considered too big for electricity to work; now there are electrically driven machines with an output of twice 5000 horse-power. The largest generators of electric current are now just about ten times as powerful as the largest generators in use when the Great War came. In many power stations in this country the output of current has increased a hundredfold in thirty years. So, you see, the age of electricity is only just beginning, for the grid scheme, that in time will bring current to everybody's door, is not yet in working order.

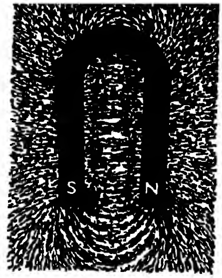
We all know that electricity is made by machines called dynamos, and that there is a dynamo under the bonnet of every car, driven by the engine, to charge the battery which provides the current for the self-starter and the lamps. To understand how a dynamo works we must know a few important facts about the relationships between an electric current and magnetism.

If a small swinging magnet such as a compass needle is placed near a wire carrying an electric current, and in such a position that it points *along* the wire, the magnet will turn and set itself at right angles to the wire. Further, the direction in which the magnet moves will depend upon the direction in which the current is passing. There is a simple rule by which the direction may be known, for if you imagine yourself to be swimming *with* the current, then, when you turn so as to face the magnet, its north pole will be towards your left hand.

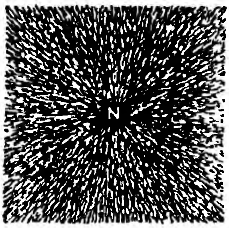
We can express this relationship between electricity and



Lines of Force between two Similar Poles



Magnetic Field of a Horse-shoe Magnet



Lines of Force radiating from a Single Pole

Magnetic Field of a Bar Magnet

Magnetic Fields

magnetism by saying that an electric current exercises a magnetic force which acts crosswise to the direction of the current. A similar force is exerted in the space between two magnets, or two electrified bodies, or between an electric conductor and a magnet. It is called a magnetic " field ", and we may picture the " lines of force " in the field as so many stretched elastics. In the ordinary way, a magnetic needle sets itself along the lines of force of the magnetic field of the great mother-magnet, the earth. If we bring a powerful magnet within a short distance of a magnetic needle, the needle is at once influenced by the new magnetic field. You can easily see these " lines of force ", if you put a thin card over a bar magnet and dust the card with fine iron filings. The filings arrange themselves

in a definite pattern, which is a map of the lines of force in *one plane* of the field. If we could get the filings to stay in position on all sides of the magnet, we should see that the magnetic field really extends in every direction.

In this experiment, every iron filing has become a separate magnet, and if we could pull the filings to pieces, molecule by molecule, we should discover that each molecule is a separate magnet also. Moreover, we should find that each molecule is a magnet of the same strength. Yet we know that these molecules in bulk can make magnets of varying strength. How is that to be explained? The explanation is to be found in the manner in which they are arranged. In an ordinary piece of magnetic substance, iron, nickel, or cobalt, the crowd of molecular magnets has no magnetism, for the magnets are arranged anyhow, with their poles neutralizing each other. But if they are brought within a magnetic field—if a piece of iron is approached close enough to a wire carrying an electric current, or if it is stroked with a magnet, the tiny magnets are turned in one direction and the ends of the piece of iron show a magnetic effect. If all the molecular magnets in the piece of iron are turned in the same direction—all the north poles pointing one way and all the south poles another, then the piece of iron is as powerful a magnet as it can possibly be.

You are not going to understand electricity just by reading a few chapters on the subject. But you can, I hope, grasp the relationships between the positively charged nuclei of the atoms and the negative electrons in their orbits. All the wonderful machinery by which we make electricity perform work for us is simply a means of jerking electrons out of atoms so as to provide electromagnetic energy waves. You are not to think that magnetism is some strange power apart from electricity. It belongs to the specks of electricity

in any and every atom. And the reason why we only observe magnetic force in a few metals, and not in all metals, is to be found in the peculiar state of electrical balance (or more strictly, *want* of balance) between the electrons shared by the molecules of those metals.

But to return to our electric current and swinging compass needle. The needle sets itself at right angles to the direction of the current, because the current has a magnetic field. We have seen that there are millions upon millions of tiny magnets in a piece of iron; therefore, if we pass a current through an insulated wire surrounding this iron, the molecular magnets will abandon their haphazard arrangement and take up positions with their poles pointing at right angles to the direction of the current. North poles will pull together and south poles together, and the result is an electromagnet. The more turns of wire there are round the iron, the more intense will be the magnetic field, and the more intense the field the greater the force of the magnet, as a whole.

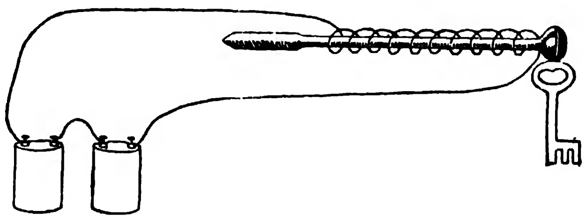
Here is a picture of an iron poker surrounded by current in a battery circuit, to show you what a very simple thing is an electromagnet. As long as the current is passing along the wire, the poker will pick up small iron or steel objects—keys, scissors, nails, and such like, but immediately the current is cut off and its magnetic field ceases, the magnetism ceases too, for the myriads of magnets in the poker stop pulling together and resume their normal haphazard arrangement.[1] We might think that while the current exists, the electrons dancing in the wire are shouting out to the electrons in the atoms of the poker and urging them to join the dance.

Electromagnets form what we may call the " vital organs "

[1] If the poker is made of steel it will become a permanent magnet.

of most electrical machinery and apparatus. Telephones and telegraphs, wireless, bells, signals of all sorts, magnetos, those are some of the things that work by the action of electromagnets, and there are others innumerable. Moreover, they are an essential part of every electric generator. I will now try to show you why this is so.

An electric current can produce a magnetic field. Remembering that electricity and magnetism are alike in origin,



A Poker as a Magnet

you will not be surprised to know that a magnetic field can produce an electric current. That immensely important discovery was made by the great Michael Faraday rather more than a hundred years ago. I call him the "great" Michael Faraday, and in truth it is hard to find words that fitly tell the measure of his greatness, whether in character or achievement. Faraday, the son of a London blacksmith, was born in 1791. He was turned upon the world at the age of twelve, poor and uneducated, but he very soon showed that great things might be expected from him. He made valuable discoveries in many branches of science, but it is to his systematic unfolding of the mysteries of electricity and magnetism that we owe the electrical wonders of these days. Faraday died in 1867.

Faraday found that when he moved a magnet about in the neighbourhood of a wire in the form of a closed circuit

—a loop of wire with the ends joined—a current of electricity was produced in the wire. Suppose we take a length of insulated wire and wind it into a coil on a hollow bobbin and join the ends. Then, if we introduce a magnet into the hollow tube of the bobbin, a current is induced in the coil, the strength of current depending on such things as the strength of the magnet, the number of turns in the coil, and the speed with which the magnet is moved. The current is only a "transient", or passing, one; it ceases as soon as the movement of the magnet ceases. If the magnet is now withdrawn,[1] a current is again induced in the wire, but this time *in the opposite direction*. So we can get a surging of electricity, first one way and then the other, by moving the coil and the magnet rapidly past one another. That is the principle of the dynamo.

Michael Faraday

In every dynamo there are three essential things. There must be a coil of wire, a magnetic field, and some form of power to move the coil across the field. The field is provided by powerful electromagnets. The simple type of dynamo used for small generators has only two field-magnets, but large generators are "multi-polar"; they have a large number of magnets arranged in a ring; and these produce a very intense field. The coils in which the current is in-

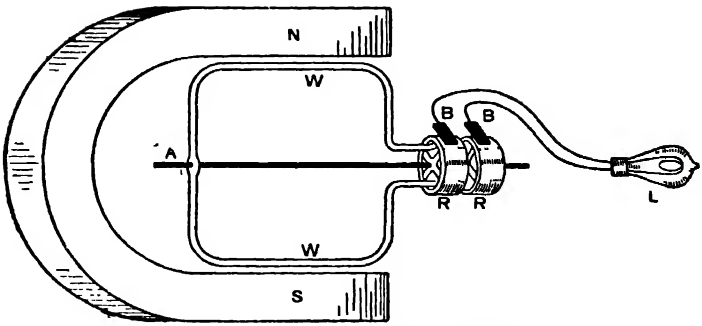
[1] It makes no difference which is moved, the coil or the magnet; it is the *relative* movement which causes the current.

duced are carried on a drum called the armature.[1] It is built up of many pieces of soft iron around which miles and miles of wire are wound. The ends of the wires on the armature coils are connected to rings, and the current is collected by strips of carbon called " brushes " which press against the rings. The brushes take the current to the switch-board, from which it is distributed to the mains.

The armature must be revolved by an engine of sufficient power to overcome the intense pull of the magnets. As soon as it starts to revolve, each turn of wire in one of the armature coils becomes the seat of an induced current as it cuts across the lines of force of one of the poles of the field-magnets, and all the coils undergo this induction in turn. But we must remember that when a magnet and a loop of wire are moved relatively to each other the direction of the current changes with the direction of the movement. The current goes one way as the loop approaches the north pole of the magnet, and the opposite way when it approaches the south pole. Consequently, the current induced in all the wire loops on the armature—tens of thousands of them—in turn changes its direction as the loops pass from one magnetic field to the next.

The result is an alternating current. It sweeps to and fro between the coils and the brushes on the armature rings. The pressure rises to a maximum in one direction, then dies away, and then rises again in the opposite direction. When you see a reference in a book or paper to a fifty-cycle generator, it means that in such a generator the current surges backwards and forwards fifty times a second. In Chapter XIV we pictured an electric current as a steady passing on of electrons by one atom to its neighbour, all

[1] Armature really means armour. The name was given to the *keeper* of a magnet, the piece of soft iron put over the poles to protect them.



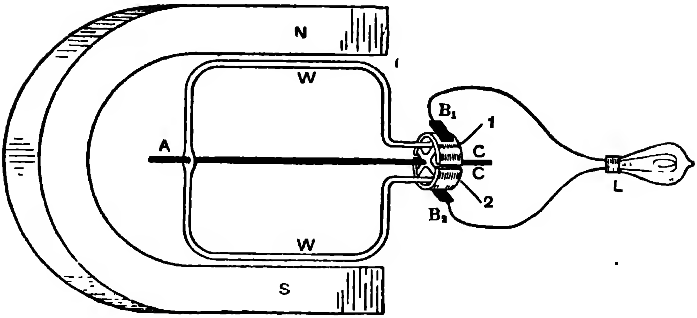
Simple Diagram of a Dynamo producing Alternating Current

N and S, North and South Poles of magnet W, W, Coil of wire. A, Spindle on which coil revolves. R, R, Rings. B, B, Carbon brushes. L, Electric lamp.

along the wire. A current of such a kind is called *continuous*, for the flow is always in the same direction. A battery gives this continuous or direct current. The movement of electrons must be very different in an alternating current. We may imagine that here the atoms are not passing on electrons all along the line; it is rather as though every atom, throughout the circuit, took an electron from its neighbour and then handed it back again.

For most of the uses to which we put electricity, alternating current is as convenient as continuous current. It can be used for driving motors, for lighting and heating. It can be distributed at much higher voltage than is possible with continuous current, and there are great advantages in that. Moreover, it is an easy matter to convert alternating current into direct current. This is done by a very ingenious device on the dynamo called a *commutator*, because it changes [1] the direction of the current. In effect, the commutator is a revolving switch, which reverses the current direction in the collecting brushes exactly in step with every alternate change.

[1] Latin, *commuto*, I exchange.



Simple Diagram of a Dynamo producing Direct or Continuous Current

N and S, North and South poles of magnet. W, W, Coil of wire. A, Spindle on which coil revolves. C, C, Commutator (split ring). B, B, Carbon brushes. L, Electric lamp.

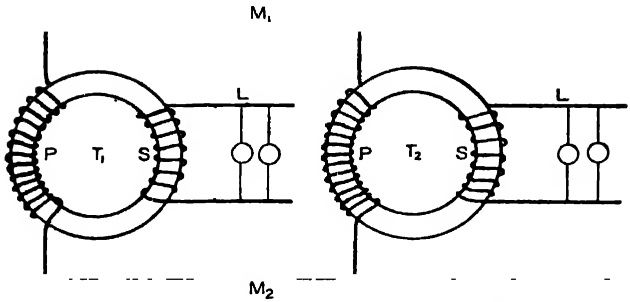
The sketches will give you an idea of how the commutator works. They show (in very simplified form) the way in which the ends of the coils are joined to the rings from which the brushes collect the current. Now, you must remember that as the coil revolves there is a moment when it does not cut *across* the lines of force in the magnetic field —the stretched elastics we spoke of on p. 218—but lies *along* them. At that moment, therefore, the coil has no current. By joining the ends of the coil to rings with gaps in them, we can make the brushes " miss step ", as it were, at the moment when the current direction is changing.

Look at the illustration. Picture the current entering the mains by the brush B1 from the coil end 1. Well, the current is surging to and fro, not only in the dynamo, but also in the circuit of the mains, of which the dynamo is part; and while the forward surge leaves the coil, the backward surge enters it by the brush B2. Then as the coil turns, the current surges again in the opposite direction and leaves by the other end of the coil. But by the time this happens *that* end of the coil is in contact with the brush

B1, so that the current again leaves the coil by the same brush as before. In short, the current always leaves by one brush and enters by the other.

I have only been able to give you a very rough outline of the principle of the dynamo, for we must keep some of this chapter for other wonders of electrical science. Our electric power station is a great treasure house of inventions, hundreds of them, and almost any one of them needs a bigger book than this to explain all about it. And the humming generators are only the beginnings of electricity—the means of jerking electrons out of atoms! The wonderful switch-board and distributing gear, the instruments for measuring and controlling the load in the cables, the cables themselves—all these are splendid tokens of man's mastery of the atom. Yet they are but the gateway through which electric power is led out to our service. A great part of that power goes to drive machines for carrying us about, in trams, trolley-buses or electric trains; and a great part is made to drive machines for making things, and to perform hundreds of different tasks that steam or gas or oil cannot do so well, or so cheaply. The electric power is turned again to mechanical power by means of electromotors.

A motor is a dynamo *running backwards.* In the dynamo we used mechanical power to turn the armature coil in a magnetic field; in the motor we pass the electrical energy thus made back into the coil again, where its effect is to convert the coil into an electromagnet. The poles of this electromagnet are powerfully attracted by the field-magnets, so that the coil is obliged to turn. Through suitable gearing the movement of the turning coil turns the wheels of our machines. The coils are wound on a " core " of soft iron

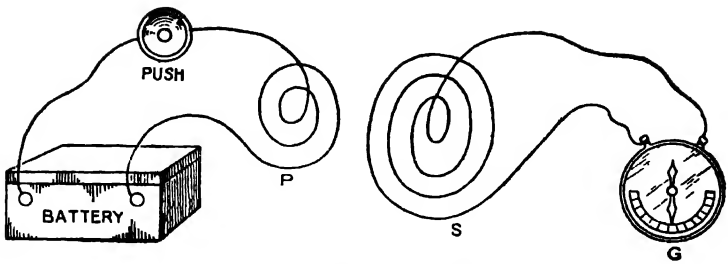


Simple Diagram of two Transformers

M_1, M_2, Mains in which a high alternating pressure is maintained. P, Primary coils arranged in parallel. S, Secondary coils. T_1, T_2, Transformers for reducing the pressure to suit the lamps L

—the armature—and when a current is sent through the wire the iron armature core behaves just like the poker on p. 221. Perhaps you wonder why the armature is obliged to turn. The answer is that the poles developed in the armature are intermediate between the poles of the field-magnets, that is, at right angles to them, so that an unlike armature pole is constantly being attracted by an unlike field pole. Thus there is a twist or " torque " on the armature and it has to go round. The effect is just the same as that on the crankshaft of a motor engine, in which each connecting-rod twists the shaft through part of a circle.

When we were talking about the " grid ", at the beginning of this chapter, I mentioned that an important feature of the national scheme is the distribution of current at very high potential. Now, except in laboratories and places where electrical research is carried on, no one *uses* electricity at a pressure of 132,000 volts. For one thing, it needs the most elaborate insulation, and if the insulation gives way, the current goes to earth with a blinding, crackling flame that destroys everything within reach as certainly as lightning. It would be quite impossible to deal with such



The Principle of Induction
P, Primary Coil. S, Secondary Coil. G, Galvanometer

a current in any ordinary building. To try to use it for power would be as sensible as using a steam hammer to hit a tin-tack, though for the matter of that, no motor could stand up to it, even for an instant.

The voltage in the overhead cables must, therefore, be reduced to a workable pressure before the current can be used. The potential is reduced in several steps by passing it through wire coils called transformers. It seems an easy way out of the difficulty, does it not? Perhaps I need not tell you that though the change in potential is simple in principle, the actual apparatus used is very complicated and costly. It is based on the same principle of *induction*, which explains not only the dynamo and the motor but also the motor-car magneto, as I shall soon show you.

Let us go back for a moment to the point where Faraday induced a current in a closed circuit by moving a magnet in its neighbourhood (p. 221). And still further back to what was said about the relationship between electricity and magnetic fields on p. 217—the bit about the swinging compass needle setting itself at right angles to a wire carrying a current. The point is that the current in a circuit has its *own* magnetic field and so it will induce a current in another circuit lying near to it, the first current acting in

this respect just like a magnet. Suppose we have a coil of wire in which a current is flowing and that we bring near to it a second coil of wire, with its ends joined. Then, if we move the coil across the magnetic field of the first, or *primary* coil, a momentary current will be induced in it. But it is not really necessary to move the coils. We can obtain the same result merely by making and unmaking the magnetic field—by switching the current in the primary coil on and off. Alternating current does this for itself.

But what have we gained by this? It looks as if we were merely duplicating in the secondary coil the current flowing in the primary coil. It would be so if there were the same number of turns in each coil, but by having more turns in one coil than in the other, we provide in that coil more

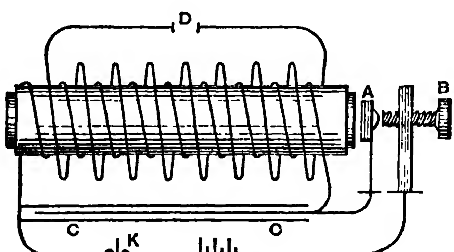


Diagram of a simple Induction Coil

The core and coils, of which the secondary is very long, are mounted on a stand, which also supports a vibrating spring A and an upright carrying a screw B. On the top of A is a mass of soft iron. Inside the base of the instrument is a condenser C.

The screw B being in contact with A, on turning the switch K the battery current passes round the primary, charges the condenser, and magnetizes the core. Thereupon the head of A is attracted to the core, the connexion between A and B is broken, the current ceases, and the core becomes demagnetized. This process is repeated with every vibration of the spring, as in the electric bell.

Lines of force being thus alternately introduced into and withdrawn from the secondary coil, momentary currents flash round it and produce a stream of sparks between the terminals D. Large coils will give sparks many inches long but are dangerous and should only be used by persons of experience.

The key K is usually fixed on the base of the instrument.

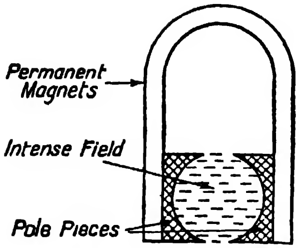
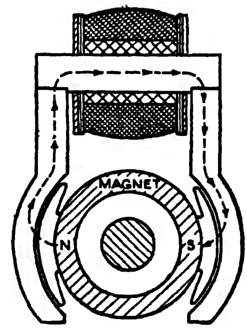
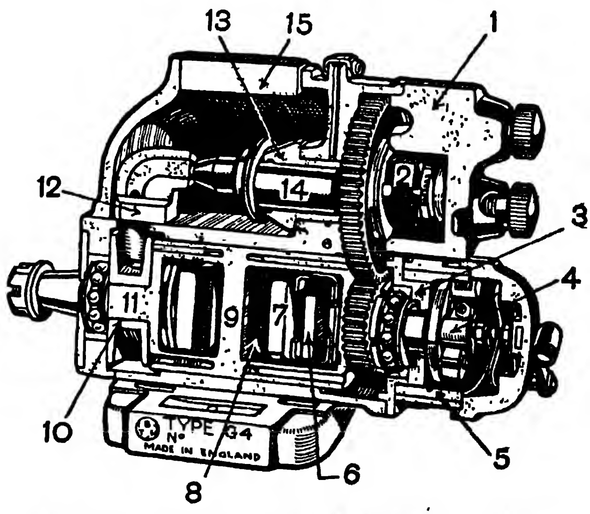


Diagram showing the principle of the low-tension element in a magneto. In the circular tunnel between the pole pieces the armature revolves.



Sectional View of Rotating Magnet Magneto

In this type of instrument the relative motion is obtained by causing a magnet to rotate so as to produce reversals of the magnetic lines of force through the fixed armature core.



Sectional View of B.T.H. Type GA 4 Rotating Armature Magneto

1, Distributor. 2, Distributor Brush Holder. 3, Contact Breaker End Plate. 4, Contact Breaker. 5, Contact Breaker Cam. 6, Condenser. 7, Secondary Winding. 8, Primary Winding. 9, Armature Core. 10, Slip Ring. 11, Driving End Plate and Spindle. 12, Collector Moulding. 13, Distributor Wheel Bearing. 14, Distributor Gear Wheel and Spindle. 15, Magnet.

places where the current can cut the lines of force in the magnetic field. In a transformer for reducing high pressure to low, the current is led from the mains into a coil—the primary—having a great number of turns of wire. As the magnetic field in this coil changes in intensity with the to and fro surge of the electrons, rising and dwindling and then rising again, an electro-motive force is generated in each of the turns of the secondary coil. This coil has far *fewer* turns, and of thicker wire. The result is that the current induced in the secondary is at a much lower pressure. The effect has been to exchange a very swift, thin stream of electricity for one broader and more sluggish.

It often happens that we wish to reverse this process, in order to increase electrical pressure. We wish to exchange a broad, slow current into a thinner but much swifter current. We still use the induction coil, but we work it the opposite way round. We pass the current through the primary coil, as before, only in this case we use a *few* turns of thick wire, and on the secondary coil we place many turns of fine wire. We know that an electro-motive force is generated in *each* of the turns of the coil and they all add to the total pressure. You must understand that we have not really put more electricity into the second coil. The total energy is the same, and we can only change the relative distribution, so that the secondary coil gives us a *smaller* flow at a higher pressure. Induction coils can be made to give enormous pressures—millions of volts—and they contain mile upon mile of wire. One such coil recently built for a laboratory has a hundred miles of wire.

Every time we want to take out our car or motor-cycle, we have to provide it with a high-tension current before it can move. We do not need much electricity to make a spark to ignite the gas in the cylinders; quite a little squirt

will do, but that squirt must be at a very high pressure. This is because a gas is a bad conductor of electricity (see Chapter XV, p. 212), and gas under compression worse still. It needs a very great electrical strain to tear electrons out of the atoms of the gas between the points of a sparking plug, though they are only $\frac{1}{50}$ of an inch apart. Fortunately we can obtain the pressure very easily on the principle of the induction coil. In most motor-cars a current at the needful pressure—about 6000 volts—is generated by a magneto.

The magneto is a combined dynamo and transformer. A coil of thick wire, wound on an armature turning between the poles of a horseshoe magnet, becomes the seat of induced currents. But this low-tension flow generated in the armature coil cannot jump the gap between the points of the sparking plug. It must be transformed by a secondary coil, which is wound round and round the primary coil, using thinner wire. About fifty times as much wire is used in the secondary winding, to make enough turns to induce the necessary high-tension current. Of course, the current in the primary coil must be repeatedly stopped and started, or there could not be any induced current in the secondary. A mechanism called a contact-breaker is therefore fitted to the armature. The contact-breaker alternately brings together and separates two pieces of platinum, to admit or shut off the flow of current from the primary winding.

The wizard electricity is being harnessed to serve us in new ways every day. But in no way, perhaps, is it so unobtrusively at our command as in our motor-cars. Press the self-starter, sound the horn, switch on the lights—what a thrilling story of scientific exploration and achievement lies behind such unconsidered acts as those!

CHAPTER XVII

Everyday Wireless

No longer ago than the beginning of the present century the words " everyday wireless " were completely meaningless. To a few scientists they would have meant a new system of signalling developed to a degree that was conceivable, though absurdly improbable. I do not suppose that even in the mind of the most hopeful pioneer in wireless telegraphy there was ever a dream more fantastic than the reality recorded in my newspaper the other day:

MOONLIGHT FROM ITALY ILLUMINES CHICAGO

That was how it was headed. There are often romantic bits of news in our papers, though we are sometimes slow to recognize them. The really romantic bits are those that set our imaginations to work and make our minds dwell on the glory and harmony of the world, and on the splendid achievements of man. Every reader who saw this heading in his newspaper must have known that romance is really alive. I will tell you the story and you can judge for yourself.

There was a big radio exhibition in Chicago and the organizers wished to associate it in a fitting way with the work of Guglielmo Marconi, the man whose name comes at once to our minds whenever we think of wireless. Marconi is an Italian; so the organizers of the exhibition said to Italian scientists, " Help us to demonstrate to our people the debt we all owe to the scientific genius of your countrymen." Then the Italian scientists thought of their great explorers who had set out to discover the secrets of the universe, and had returned with great riches; in honouring

Marconi, they would honour also the memory of the pioneers. Now, among many great sons of Italy there is one, in science, greatest of all—Galileo. It was decided therefore that he should open this radio exhibition in Chicago.

They took from the National Museum in Florence, where it is carefully treasured, the first telescope made by Galileo, in 1610. I told you about it in Chapter VIII. They set up the telescope again in Galileo's old home, the Observatory of Arcetri, in Tuscany. There it was, pointing at the midnight sky, just as in the brave old explorer's time, three centuries before. But these modern scientists were using it for a purpose Galileo could never have imagined. They pointed it at the moon, and the moon poured into it a stream of the radiant energy it borrows from the sun. The cold pale moonlight was focussed by the telescope on to a photo-electric cell, which changed the light energy into a tiny impulse of electric energy. This impulse having been "amplified" by the Florence wireless station, was flicked on to the long-distance wireless station near Rome. Rome sent it to Chicago, five thousand miles away. There this energy impulse was received by a special apparatus, which in its turn transmitted it to another apparatus controlling the electric lamps of the radio exhibition. That was how the moonlight shining upon Italy came to switch on the lights in a hall in Chicago.

The first thing we have to get hold of in trying to understand the marvels of wireless is this: if we excite atoms so that their electrons are violently disturbed, they give out a charge of electromagnetic energy that travels with a wave-motion. The waves extend in all directions, and they set up corresponding disturbances in the atoms they bump against. We say that the wave-motion is a vibration in the ether; but, as I told you in Chapter VII, we have no possible

means of finding out anything about the ether, nor even if it exists. So we ought rather to say that the energy-squirts of the vibrating electrons behave exactly like waves, but that we do not know anything about the substance in which the waves travel.

However, our ignorance about the ether does not matter much. The wave-motion of radiant energy has come into chapter after chapter of this book,[1] and it might be worth while to read again what I have already told you about waves. The existence of electromagnetic waves in space was suspected by Michael Faraday, but it was left to a great scientist named James Clerk Maxwell, Faraday's successor in electrical research, to put forward a theory that explained the waves, and to show their close relationship to light. This was a very wonderful achievement, for Clerk Maxwell knew no way of producing the waves, or of demonstrating their existence, by any sort of practical experiment. But then he was a very wonderful man, and the most brilliant mathematician of his age. He was born in Edinburgh in 1831, and died in 1879. We owe a great debt to his memory, for it is largely due to him that wireless has become possible, and many other electrical wonders. Dull boys may take heart from the example of this great man, who was so stupid when he first went to school that he was nicknamed " Dafty ".

Clerk Maxwell died before electromagnetic waves were made use of to carry messages without wires. The discovery that they could be produced at will and detected over a distance was made by Professor David Edward Hughes, whom we met in Chapter XIII as the inventor of the microphone. Professor Hughes was only laughed at for his pains, and told that his discovery was an impossibility. But a

[1] Chap. VI (Wave-length, Frequency), pp. 69, 71, 80; Chap. X (Spectroscope, &c.), pp. 127, etc.; Chap. XIII (Waves in Air), p. 173; Chap. XV (Kinds of Radiant Energy Waves), p. 212.

Heinrich Hertz

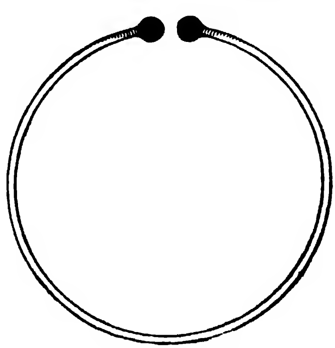
year or two later a young German scientist named Heinrich Hertz was able to show how the waves could be set going, and caught again, by very simple apparatus. By means of a battery and an induction coil Hertz produced a series of electric sparks, as thousands of electricians had done before him. But he went further; he caught the sparks again in another part of the room. The oscillating current (we saw how the electrons must be made to surge to and fro in an induction coil, in the last chapter) produced a succession of energy impulses that set up waves that he was able to detect with a broken ring of wire. The wave-motion excited the atoms in the wire, and the electrons surged to and fro as crest and trough followed each other. If the ring had been a complete one there would be no means of detecting the movement of the electrons; but there was a little gap in it, across which some of the electrons were obliged to jump. In making this jump they produced a tiny spark.

You see that the principle of wireless is not so difficult after all. If I had a battery and coil, or any other apparatus for making an oscillating discharge, a little dynamo, say, and you in another room, or another house, had Hertz's broken ring detector, I could make the waves carry messages to you. A Morse key, or a bell-push, would serve me to control the sparks, so that I could send out long or short trains of waves,[1]

[1] A train of waves is simply a group produced by one discharge. It has nothing to do with the frequencies of the waves.

in a prearranged code. You would find it difficult to catch the sparks on your detector, it is true; and you might not see the sparks even when they were there! Also, some of the signals would not come through to you properly because, although the waves can penetrate most things, the walls of houses, for instance, some of them would be absorbed and some reflected. Some of the reflected waves would cancel out some of the oncoming waves; where the crest of one happened to meet the trough of another it would " fill it up ", producing a calm at that point.[1] Our prearranged code might not come to much! We must look for a better means of detecting the signals.

A French scientist, Professor Edouard Branly, put into our hands a much better kind of detector in the *coherer* he discovered in 1890, a few years after Hertz's experiments. This is a little glass tube containing some fine metal filings. So long as the filings are loose, they form a very bad electric conductor; but when the waves from a spark oscillator fall on to them, they cling together, or cohere, and then they form a good conductor. A very simple way in which you could receive my signals would be to put a coherer in an electric-bell circuit. It acts like the bell-push, keeping the current from the battery shut off until it is wanted. When the electric waves I send out reach the coherer the current can pass and the bell rings. When I stop the waves, and the filings in the tube fall apart again, the current from the battery is shut off.



A Ring Detector

[1] The place where the crest of one wave fills the trough of another, so that there is no vibration at that place, is called a *node*.

Such a primitive form of wireless communication is not of much practical use, but it was the best that had been discovered forty years ago. It gave the scientists of those days something to work on, and they were very quick to invent improvements. Some of the most important improvements were made by Marconi, then a young man of twenty-one.

Marconi

The first of these was made in 1895, when he connected one end of his spark producer to earth (in his father's garden in Italy), and the other to a wire placed at a height above the ground —an aerial, as we should now call it. He connected the ends of his receiving circuit in like manner to earth and aerial, and found that he was able to communicate over far greater distances. He also invented a magnetic detector, much more sensitive than Branly's coherer, and in a few years wireless stations were at work in many parts of the world.

In 1901, only seven years after Marconi's experiments in the garden, he and two assistants, Mr. G. S. Kemp and Mr. P. W. Paget, travelled to Newfoundland specially to receive the first experimental wireless signals sent from Cornwall across the Atlantic. When, in 1931, the three colleagues met to celebrate the thirtieth anniversary of that great experiment which inaugurated world radio, Marconi broadcast a speech in which he told the story of the first transatlantic message. He said: " We flew a kite carrying an aerial; and at about 12.30 p.m. a succession of three faint clicks—corresponding to the prearranged signal—sounded distinctly in the tele-

phone held at my ear." Those "three faint clicks"—the Morse signal for the letter S—flashed across more than 2000 miles of ocean represented an achievement that was rightly considered very wonderful, and served to draw attention to the great possibilities of wireless telegraphy, though no one then realized how full of promise they were. The event that really stirred popular imagination was a collision between a liner and an emigrant steamer in the Atlantic in 1909. The liner's wireless signals of distress brought rescue for all the passengers, and when people read about the rescue, they knew that the new mysterious power to talk across the ocean wastes was a truly beneficent gift of science.

I am trying to show you how swiftly and steadily wireless telegraphy has marched to maturity. One reason for this is its extreme usefulness, but the rapid development is chiefly the result of patient study and experiment. The story of wireless shows us what can be done when clever people put their heads together, for its triumphant progress is largely the outcome of teamwork. The great industry that has grown up to provide receiving sets so that millions can enjoy the entertainment of broadcasting is only a part of the business of wireless. When we listen-in to concerts and talks, we must not mistake our part of wireless for the whole of it, nor even the most important part. There is a great deal that many of us never think about, unless we happen to have need of it. Unless you are interested in shipping, for instance, you may not know that you can communicate by telephone with a friend on board almost any ship sailing within 200 or 300 miles of British coasts. Passengers on the large liners can talk to their friends by word of mouth over much longer distances, and I do not suppose it will be many years before this ship-to-shore

wireless telephone service becomes extended so that we can ring up a friend anywhere upon the high seas.

But though, as yet, we cannot actually speak by word of mouth with every and any ship in any part of the world, we can send a wireless message from a telegraph office to any ship over 1600 tons, a radio-telegram, it is called. The transmission of such messages is part of the work of the post office " beam " wireless service, which maintains communication with the whole world. It is called beam wireless because the waves are concentrated in a particular direction by focussing and reflection like a beam of light. The beam wireless stations are situated in different parts of the country, and are used for official and commercial messages; but in 1932 a wonderful beam station was opened at Daventry for transmitting the broadcast programmes to every corner of the Empire. On the hill, 500 feet high, on which stand the giant 500-ft. masts carrying the aerials of the National Broadcast transmitter, there is also a forest of shorter masts [1] in rows which face South Africa, West Africa, Canada, the Far East, Australia. How would you face Australia? You could look across Northern Europe, Siberia, and part of India, or across the Atlantic, America, and the Pacific. The beam aerials for sending speech and music to Australia look both ways, too, for sometimes the conditions are better on one route than another. Just as a beam of light spreads out like a cone, so does a beam of wireless rays; and you may be interested to know that the base of the beam that sweeps round the curved surface of the earth is about 2000 miles across when it reaches the radio receivers in Australia.

There is not space here to tell you of more than a very few of the useful applications of wireless, but I must mention

[1] The reason why the long-distance aerials are shorter than those of the National transmitter is because the Empire broadcast is on a very short wave-length which requires less power.

SENDING PICTURES BY TELEGRAPH OR WIRELESS—I

At the top is shown a reproduction of the photograph which is placed in the drum of the transmitter, and below is a reproduction of a print of the negative as it comes from the receiver drum. See enlargement of this photograph on the plate facing p. 256. See also pages 245 and 246.

one that is of very great importance to seafaring folk. I am sure you know that of all the perils of the sea, dense fog in busy waterways is deadlier than any. The hydrophone, described in Chapter XIII, helps ships to keep clear of shoals, but it cannot tell them their exact whereabouts. A wireless lighthouse can do so, however, even though the light it sends out is not visible. The first " talking lighthouse " was erected a few years ago on the Firth of Clyde, and has proved itself of great value. It is entirely automatic, but whenever a fog descends it sends out wireless telephone signals as well as the usual blasts of the fog-horn. Any ship with the necessary receiving instrument hears the word " Cumbrae ", which is the name of the lighthouse, and this announcement is followed by a voice which counts out in cables,[1] distances up to five miles. There are intervals of silence during the counting, and immediately before each mile is spoken a bell is sounded. Now, the interval between each figure of the count is the time sound takes to travel a mile. So you can see how the signals tell the ships how far away they are, by comparison with the air-borne fog blasts.

There are wireless direction finders for guiding aircraft pilots. The pilot has a telephone receiver at each ear, each telephone being connected to a separate aerial. The aerials are of the frame type similar to those used in portable wireless sets, which only receive signals when one end is pointing directly at the sending station. Therefore, if the pilot is heading direct for the station sending out the signals, he will hear them at their strongest, and at equal strength in both ears; while if he deviates from his course there will be a falling off in signal strength in one ear or the other. In a much more complicated system, two stations compare the strength and direction of a pilot's signals, and the com-

[1] A cable is a nautical measure of 100 fathoms, i.e. 200 yards.

Ambrose Fleming

parison enables him to be given by telephone his exact bearings, even when he is flying thousands of feet above the clouds.

Some pages back I told you of the simple apparatus by which wireless became established. I must now explain that the real wonders of present-day wireless, such as broadcasting and radio-telephony, are chiefly due to an invention which made it possible to convert the oscillating surges of electrons in a receiving aerial into a *continuous* current of electricity strong enough to work a telephone. This invention was not made until 1906, when Dr. J. Ambrose Fleming, Professor of Electrical Engineering in University College, London, produced the mysterious kind of lamp, called a valve, which plays such an important part in wireless. The proper name of the lamp is *thermionic valve*, which gives us a clue to its nature. A valve, we know, is a door, which opens in one direction only,[1] and *thermos* is the Greek word for heat, as in *thermometer*. There remains *ionic*, which comes from another Greek word, *ion*, a wanderer. What on earth are " heat wanderers "? Well, if you remember what you read in Chapter XV about the cathode-tubes used for X-rays, you will be able to make a good guess. The wanderers are electrons.

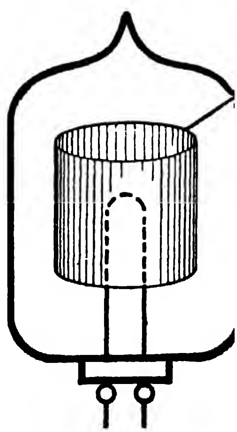
Professor Fleming was interested in a very strange effect caused when a little metal plate was introduced between the legs of the filament of an electric lamp. The great American inventor Edison had found that a small current flowed from

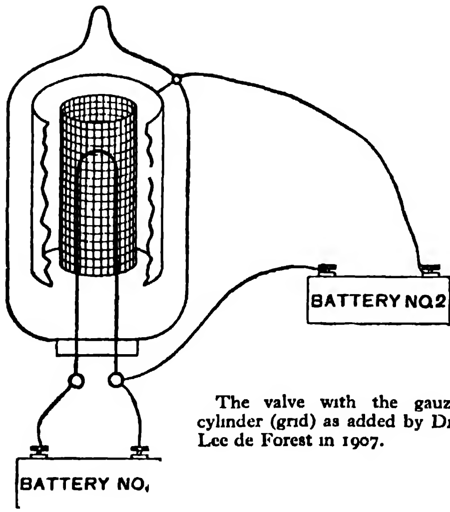
[1] Latin, *valva*, a leaf of a *folding*-door.

such a plate, although it was quite unconnected with the filament of the lamp, and so the phenomenon became known as the Edison Effect. What happened was that electrons were discharged by the hot filament and collected in a crowd on the plate, but this was not discovered until many years later.

Professor Fleming made a lamp with a little cylinder of metal surrounding the filament, but entirely free from it. He found that when an alternating current was turned into the lamp only a *part* of it was allowed to pass through. The forward surge of each wave came along and passed through the " door ", which closed itself on the backward surge and shut it out. Thus, by only admitting the current flowing in one direction, the to and fro alternations were changed to a continuous current. We say that the valve *rectifies* the current.

We can understand the action more clearly if we imagine a valve from our wireless set, in its relation to the aerial. Our valve differs from Fleming's inasmuch as it has a *grid.* This is a gauze cylinder placed between the filament and the plate, as shown in the illustration (p. 244). It was added by an American inventor, Dr. Lee de Forest, in 1907, and it is the genie of the lamp which has brought the joys of broadcasting into millions upon millions of homes. You know that the filament of the valve must be heated in order to "ginger-up" the atoms, so that some of the electrons are sent a-roaming. We use a low-tension battery to do this. But there are two more circuits


A diagram of the original Fleming Valve, 1906



The valve with the gauze cylinder (grid) as added by Dr. Lee de Forest in 1907.

besides this. There is the aerial circuit in which the grid is placed. This is not directly connected with the grid but to the secondary winding of an induction coil, of which the primary winding is really part of the aerial. When the waves reach the aerial, they excite a to and fro movement of the electrons in the primary of this coil, and induce a corresponding movement in the secondary.

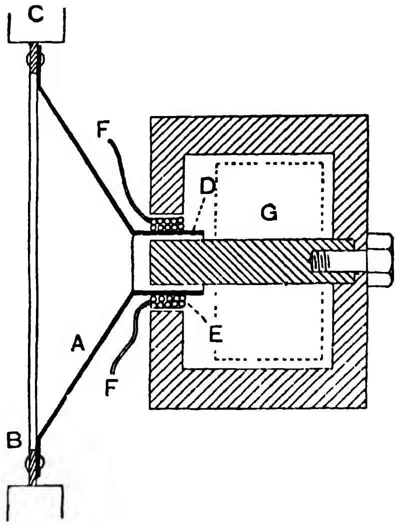
The third current passing through the valve is the plate circuit. The plate is also called the anode, because it is connected to the positive terminals of the high-tension battery. This is the current for working our telephone or loudspeaker, and is the one we are using the valve to control. Let us see how the control comes about.

The electrons set loose from the heated filament crowd upon the grid, giving it a negative charge.[1] Meanwhile the battery is also forcing electrons to gather on the *plate*. Very awkward for the electrons, for they hate each other! Like repels like, we know. Consequently, the battery current cannot reach the plate for the way is blocked, the valve is shut. How can it be opened again? Why, by giving the grid

[1] Electrons *are* negative electricity. Read Chapters XIV and XV again, if you are not sure of this.

a positive charge so as to relieve it of the crowd of mutually hostile electrons. The means of relieving it comes on the waves that reach the aerial from the wireless station. As trough follows crest, the electrons in the aerial rush first in one direction and then in the other.

The grid is connected to the aerial, as we have seen. So, when the electrons surge one way in the aerial they rush to the grid and overcrowd it, giving it a negative charge and therefore stopping the flow of current through the valve (the plate circuit) by their repulsive force. An instant later the electrons in the aerial surge in the opposite direction, and the jostling electrons on the grid are dragged back. Well, we know that a shortage of electrons equals a positive charge,



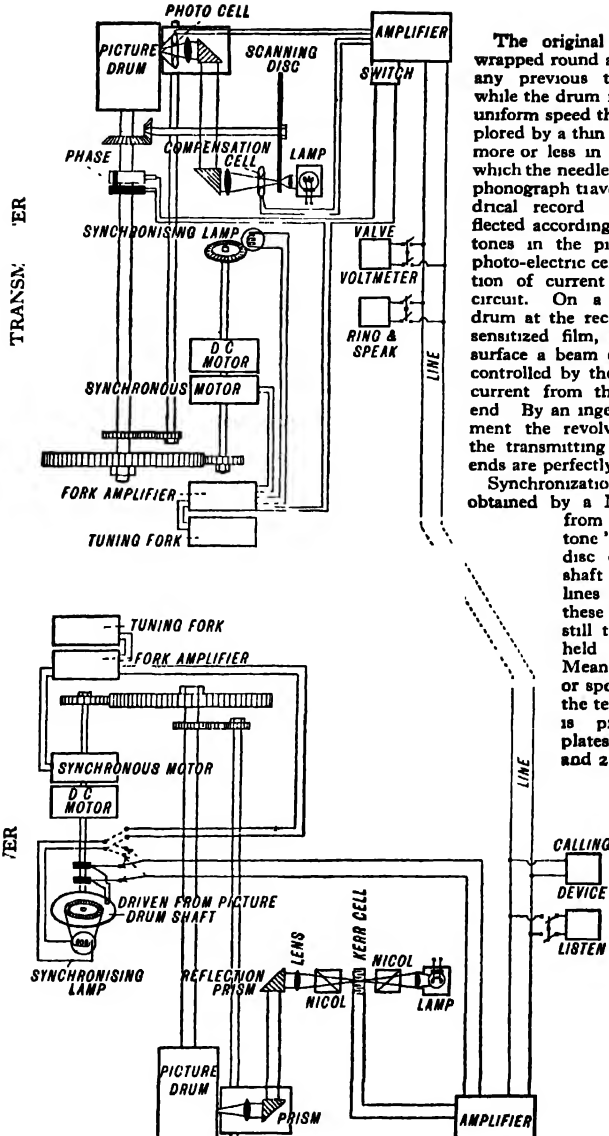
Diagrammatic Section of a Moving Coil Loudspeaker

A stiff diaphragm A in the shape of a truncated cone is suspended by means of a rubber or leather ring B from a fixed support C so that it is free to move slightly in the direction of its axis.

On a light thin tube D attached to the apex of the cone a coil E is wound consisting of two or more layers of fine insulated copper wire terminating at F F. An intensely powerful "pot" magnet, which may be permanent or energized (if the latter, an exciting coil G shown in dotted lines would be fitted and fed from a direct current source) has its poles so arranged that a narrow annular gap separates them.

The magnet and cone supports are relatively mounted so that the coil E is capable of moving within the gap, but is not touching the poles. On connecting the terminals F F to the output from a radio set using a suitable coupling device, electro-magnetic forces are set up in the coil corresponding to the current variations. These being transmitted to the diaphragm cause it to vibrate and so emit sounds similar to the original broadcast.

and so the battery current can pass from the filament to the plate. Now comes another wave, and once more the electrons stop the current. The valve opens and



The original photograph is wrapped round a drum, without any previous treatment, and while the drum is revolved at a uniform speed the picture is explored by a thin beam of light, more or less in the manner in which the needle of the old-time phonograph traversed the cylindrical record This light, reflected according to the varying tones in the picture on to a photo-electric cell, causes variation of current in the output circuit. On a corresponding drum at the receiving end is a sensitized film, and across its surface a beam of light travels controlled by the oscillations of current from the transmitting end By an ingenious arrangement the revolving drums at the transmitting and receiving ends are perfectly synchronized.

Synchronization (tuning) is obtained by a Neon lamp lit from the "fork tone" lighting a disc on the motor shaft with radial lines on it. When these appear to stand still the machine is held by the fork. Means of signalling or speaking between the terminal stations is provided. See plates facing p. 241 and 256.

Diagram showing the arrangement of the Siemens-Karolus-Telefunken apparatus for transmission of photographs over a telephone line, a radio link or submarine cable.

closes with each successive wave-impulse which reaches the aerial. On a wave-length of 1000 metres the valve " oscillates ", that is opens and shuts, 300,000 times a second. If you can remember that a wave-length of 300 metres has a frequency of one million, you have a useful standard by which you can calculate the frequencies of other wave-lengths.

We use valves for *amplifying* the wireless signals, as well as for rectifying them. Several valves are arranged in such a way that after the battery current has picked up the oscillations by passing through one valve, it is enlarged or made fuller by passing it through the others. The valves are not directly connected, but by means of transformers the current is induced in each of the valves in turn, and finally in the telephone or loudspeaker.

And how does the speech or music get into the wireless waves to begin with? The waves that reach our aerials are not perfectly smooth waves; they are covered with tiny ripples, like the ripples we might make by blowing on the waves made by a stone thrown into a pond. These little ripples, or " modulations " as they are called, are produced on the carrier-wave by a valve which alters the intensity of the energy sent into the transmitting aerial. The valve is controlled by the microphone, which alters the amplitude of the aerial current in exact accordance with the variations in the pitch and strength of the sounds which reach it.

We started this chapter with the story of how Galileo's telescope turned on the lights in Chicago, which showed that light-impulses can be used, like sound impulses, to modulate a wireless wave. The power to change light into electric energy, and back again to light, gives us a way of sending pictures by wireless. It also gives us the marvel of television, which is the wireless transmission of actual

scenes. Perhaps we can better understand this marvel after a visit to the cinema. Let us go to the Talkies.

CHAPTER XVIII

Science at the Cinema

If it fell to our lot to explain to an ignorant but intelligent savage the meaning and purpose of science, the best thing we could do would be to take him to the cinema. No other single roof covers so much concentrated science as the up-to-date "talkie" house, except a science museum or a science laboratory. The cinema is so chock-full of science that we are apt to forget that science is there at all! For most of us the show's the thing, and the only thing we go to see or think about. Yet I fancy that the thrills we get at second-hand from the screen are poor things compared with the thrills we could get from the operator's box, if we cared to take the trouble to examine the mysterious forces of light, sound, and electricity brought together and controlled therein.

I need not tell you much about the making of moving pictures, because I am sure you know the general principles. The photographs are taken on a long ribbon of celluloid film, which unwinds from one big reel in the camera on to another big reel. As the movie-man winds the handle of his camera, the shutter of the lens is opened and closed, and at the same time the film is brought into position for the next exposure. Although the film is wound continuously from one reel to the other, it really moves with a series of jumps or jerks, for there is a little loose loop of film which is always ready to be brought before the lens. The loop

comes into position at the moment when the shutter is closed. This happens sixteen times a second. When the whole reel of film has been exposed, it is developed, and becomes a negative, from which as many positives can be printed, on more ribbons of celluloid film, as may be needed. As you know, the camera inverts the images shown to it; but the cinema projector inverts them again, and they thus appear the right way up on the screen.

The projector deals with the film just as the camera did. The intense light of an electric arc is concentrated on the film, and lenses bring the rays passing through the picture to a focus on the screen. The ribbon is unwound from the full reel on to an empty one by little toothed wheels which engage in holes on the edges of the film. As before, there is a loose loop of film; and where it passes between the lenses there is a device called a " gate ", which jerks each successive picture into position. At the moment one picture leaves its place between the lenses, and the next comes on, a shutter shuts out the light. The pictures are thrown on the screen at the rate they were taken at—16 a second. Every picture is on the screen for $\frac{1}{32}$ of a second; and there is an interval of $\frac{1}{32}$ of a second between one picture and the next, when the screen is in total darkness.

Such is the very simple way in which the movies fool us into the belief that we are seeing things in continuous motion. Really, the motion is discontinuous; we see a great number of snapshots shown to us in rapid succession, but with a gap between each. How is it that we are not conscious of the gap? Well, how is it we are not conscious of the jumps in an electric lamp? We know that an alternating current sweeps to and fro about 50 times a second, reaching a peak or crest of intensity and then dying away to nothing. Why don't we see the lamps flashing on and off? The

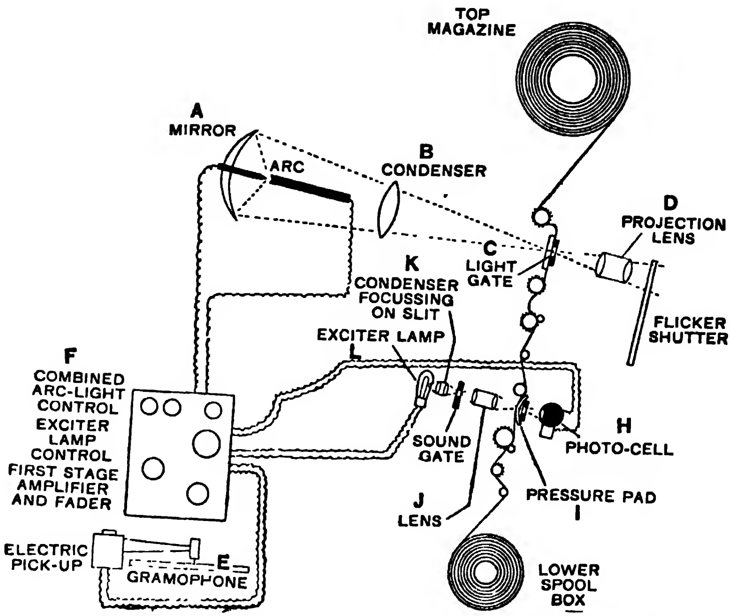
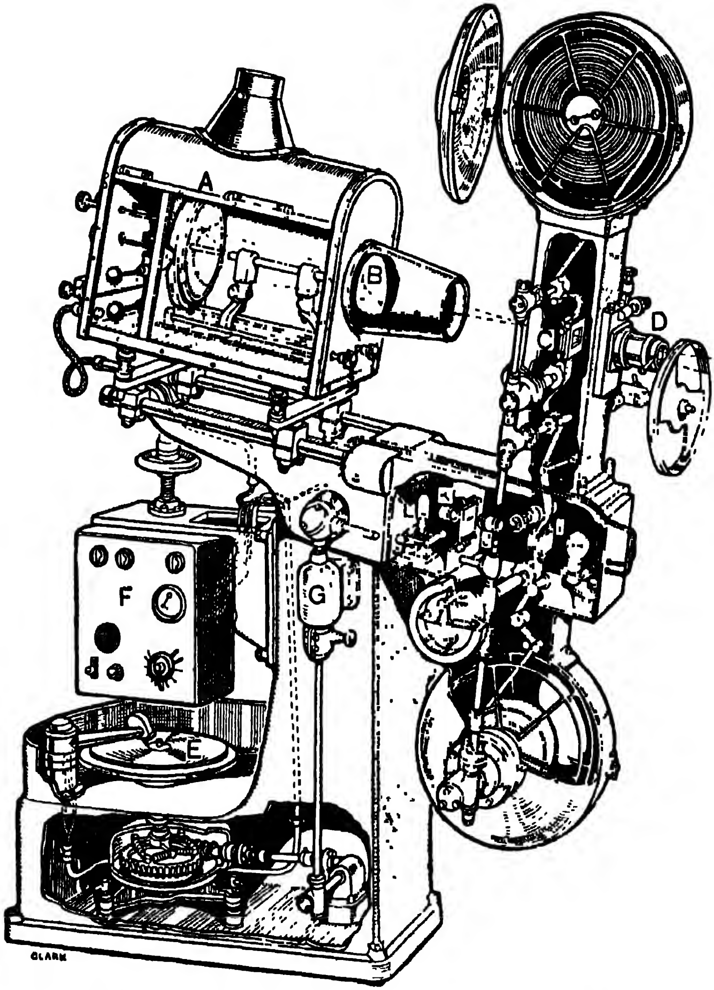


Diagram of a Cinematograph fitted with Sound Projection Apparatus.
See opposite page

reason is that when the retina of the eye receives a light-message it hangs on to it for an appreciable time. It cannot get rid of the impression nearly so fast as it received it. So we think we see things happening long after they have stopped happening. We can see a flash of light that only lasts $\frac{1}{1000}$ of a second, but we cannot get rid of the mental picture of the flash in less than $\frac{1}{10}$ of a second.

This inability of our eyes to dismiss pictures as quickly as they pick them up is called *persistence of vision*. Anyone can demonstrate it to his own satisfaction. The easiest way is to revolve a glowing stick or match-end, when we shall see something that does not exist! We shall see a glowing circle, but we know that no circle is really there, but a



Section of a Cinematograph fitted with Sound Projection Apparatus. For names of the parts see schematic diagrams on opposite page. G is the motor and clutch for connecting up gramophone. See also illustration of sound track on p. 259.

glowing spot that constantly changes its position. Or—a better way to fill in an odd moment—we can take a small card and make a little hole near the right-hand edge and another near the left-hand edge, both the same distance from the top and bottom edges. Next, fasten short pieces of string to the card by knotting them through the holes. Now take pen and ink and draw a bird cage on one side of the card and on the other side a bird. Then, if you hold the strings and quickly revolve the card by twiddling them, you will not see separate pictures of cage and bird; you will see the bird in the cage, for your eyes cannot get rid of the impression of one picture until long after the impression of the other is brought to it. The effect, therefore, is the same as if you saw both at once. But for this " time lag " there would be no movies, nor television either, about which I hope to tell you something.

Up in the box at the back of the hall, the cinema operators (they call themselves " projectionists ") have charge of most beautiful but very complicated apparatus. Even before the coming of sound films, the cinema projector had attained a very wonderful degree of mechanical perfection. It was an optical wonder and an engineering wonder as well, for its machinery was obliged to run with absolute smoothness, steadiness, and noiselessness, and it also embodied quite a pretty piece of electrical work, in the connexions for making and " striking " (i.e. stopping) the arc which provides the intense light required to illuminate the screen many feet away. But with the coming of sound films, the projectionists were called upon for a staggering expansion of knowledge and skill. They were assumed to be not merely opticians, electricians, and mechanicians, but chemists, sound engineers, and wireless experts of the highest order. They were put in charge of appallingly complicated apparatus,

of a sensitive delicacy entirely beyond the comprehension of ordinary mortals. And when this prodigious combination of all the sciences fails to function properly, they are expected to put it right without the audience being any the wiser! When we take off our hats in the cinema, the act should be a tribute to the men beside the projectors.

There are always two projectors and two projectionists. " Feature " films are on several reels, perhaps as many as ten; and while one reel is being run through one projector, the next reel is being got ready on the other. As the first reel approaches the end, the projectionist signals to his assistant, who has everything ready on the second machine; and at the exact moment when one reel is finished the other projector carries on with its successor. The change-over is so smoothly done that the audience knows nothing at all about it.

Nor, I fear, does the audience—or most of it—know much or care much as to how and why the speech and music comes to it. Well, the talkies are one of the highest achievements of science, as I have already said (which is not to say that they are the most useful achievement). And the science in them is so highly concentrated that it is hard to follow, unless we know a good deal about light and optics, sound, electro-magnetism, and chemistry. Yet there is so much romance tucked away in the bewildering assembly of apparatus in the projection-room of a cinema that we must make an effort to understand how it works.

The sound can come in either of two ways, and in any big picture it may come by one way at one moment, and by the other way at another moment. One way is a gramophone record and the other is the film itself. As the gramophone record is the simpler we will look at that first. Beside the projector there is a gramophone worked by an electric

motor and connected with the projector by gearing in such a way that the film and the record keep in exact time together, or *synchronize*.[1]

This gramophone is a very beautiful mechanism, partly electric and partly mechanical, but we must look particularly at the method by which the sound-impressions on the record [2] are handed on to the audience. This is done on the principle known as electric pick-up. In the ordinary gramophone sound-box the needle as it traverses the grooves of the record vibrates a diaphragm to reproduce the original sound waves. Electric pick-up dispenses with the ordinary sound-box. The needle is attached to a tiny magnet suspended between the poles of a powerful electromagnet. As the needle vibrates, it sets up varying electric currents in the coils of the electromagnet, the current variations being exactly in sympathy with the vibrations. There is nothing whatever to be heard as the needle traverses the record, for the needle and the magnet are changing the vibrations into electric currents, not into sounds. These currents are much too weak to operate any sort of sound-producing instrument; that is, they cannot themselves be translated into sound waves. But they can be treated just as the modulations of the wireless waves are treated. They are amplified by passing them through valves so that they can control the fluctuations of another current powerful enough to vibrate loudspeakers.

This system provides very faithful reproduction of the sounds originally recorded, but it has the drawback that if the film breaks it is impossible to get the sounds perfectly into step again with the picture. When the projectionist has mended the film, he must either run it again from the

[1] Greek, *syn*, together; *chronos*, time.
[2] The record is not quite like the sort we play on our own gramophones. The talkie records are larger; they start in the middle and travel towards the edge and they revolve at less than half the speed of ours.

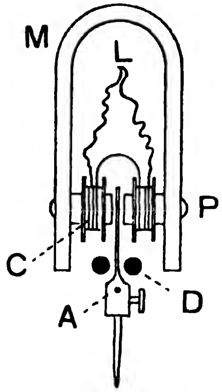
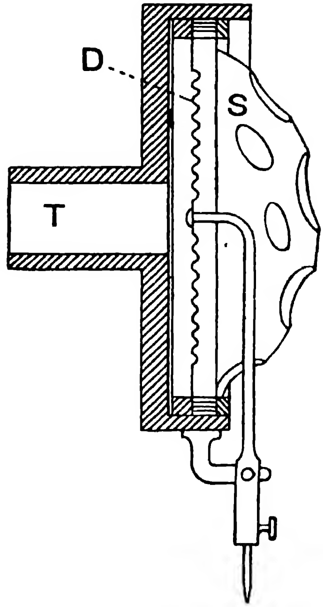


Diagram showing the working of an Electric Pick-up for Gramophone Record Reproduction.

A small and light but very powerful magnet M, made of cobalt steel, is fitted with two soft iron pole shoes P, having a narrow gap between them. The pole shoes carry one or two small bobbins wound with fine insulated copper wire. A light pivoted armature A carries at one end a gramophone needle, the other end being free to oscillate in the gap between the pole shoes. The whole pick-up is attached to a pivoted arm The needle, following the wavy groove in the record, causes the armature to oscillate between the pole shoes, which induces varying currents to flow in coils. These currents are led away at L and after being amplified are reproduced in the loudspeaker. Excessive movement of the armature is restrained by two rubber dampers D.



Section of a Mechanical Sound-box

D, Corrugated diaphragm
S, Perforated shield or tone reflector.
T, Tone-arm.

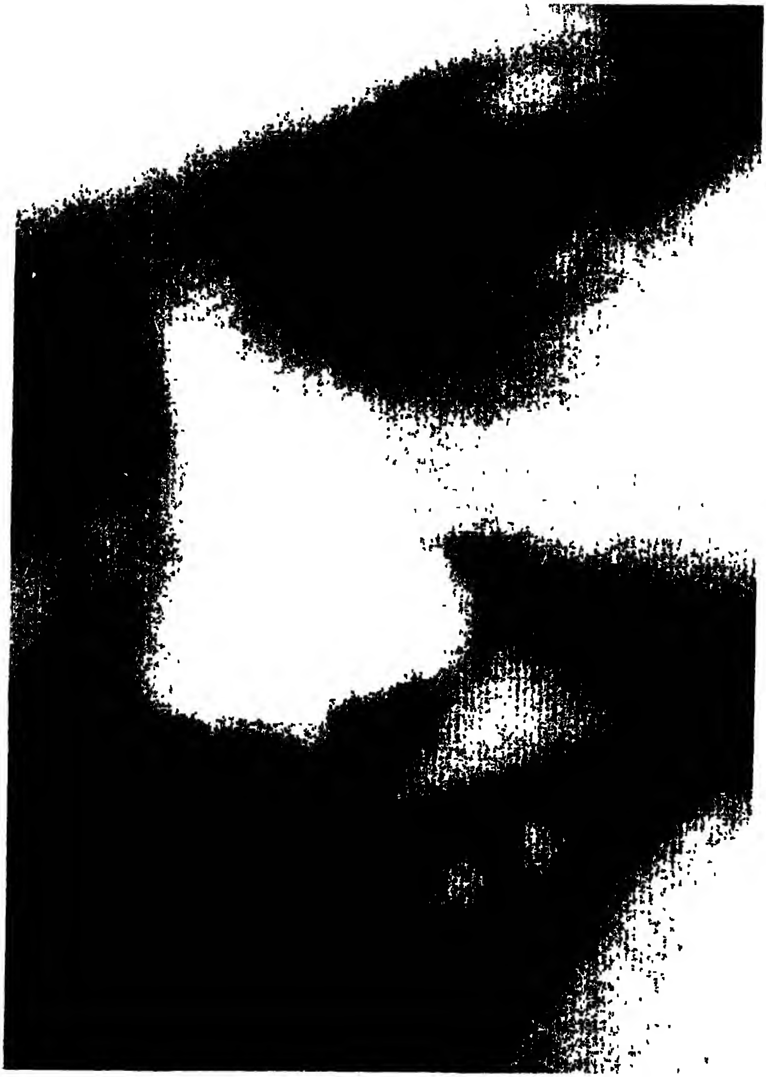
beginning of the record, or show it as a " silent ", or omit it altogether and go on to the following record. The ability always to keep sound and action in perfect synchronization is one advantage of having the sound actually on the film. The processes by which a beam of light is translated into sound are much more complicated than the electric pick-up. Unless everything works perfectly from the beginning the sounds reproduced may be thick or woolly.

We can only glance at the wonderful way in which the sound comes to be imprinted on the film and turned again by the projector into speech and music. This great marvel of everyday science depends on the function of a most beautiful device often called " the electric eye ". Scientists speak of it as the *light-sensitive cell.* You may remember that I touched on some of its wonders as far back as Chapter II. We may start our inspection of the light-sensitive cell by first glancing at the " moon element ", selenium.[1]

I have told you, from time to time, about some of the ways in which the energy of light excites the atoms of the substances around us, and changes their electrical balance. The whole science of photography, for instance, depends upon such changes. So you may not be surprised to hear that when light falls upon the atoms of certain of the elements it makes them more ready to pass on electrons, in the way of an electric current. That is to say, certain elements become better electrical conductors when they are stimulated by light. This change is shown by a few of the metals; our old friend sodium is one of them, calcium, potassium, and cæsium are others. It is most noticeable, however, in selenium, which is not a metal but an element closely akin to sulphur.

The electrical resistance of selenium is altered by light to a very remarkable degree. If a piece of selenium protected from light is placed in an electric circuit, hardly any current will flow. But the resistance of the selenium is lessened exactly in proportion to the amount of light that falls upon it, and in a sufficiently bright light it becomes an excellent electrical conductor. This property of selenium provides us with a very easy way by which light may be made to

[1] Greek, *Selene*, the moon. The element was discovered in 1817 by a chemist named Berzelius. He called it selenium because it was rather like the " earth-element ", tellurium.



L. 712

SENDING PICTURES BY TELEGRAPH OR WIRELESS—II

An enlargement of the lower picture on the plate facing p. 241. The space between the lines is the track of the light. The dark vertical lines are due to a slight leakage of light each side of the track. By courtesy of the *Glasgow Herald.*

control variations in an electric current. Unfortunately, when we want to control variations occurring as rapidly as the frequencies of sound waves, selenium is not entirely satisfactory. It does not respond quickly enough.

Here I must tell you that the fact that light can be made to control the strength of an electric current is of very great importance in many ways quite unconnected with the talkies. Scientists have been working on the problem for years, and long ago succeeded in producing light-sensitive cells so amazingly delicate that they could detect the light of a candle miles away, and even the light of invisible stars. Such light-sensitive, or "photo-electric" cells, have nothing to do with selenium, and are infinitely more rapid in their response to variations in the intensity of a source of light.

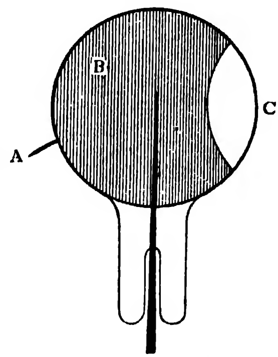


Photo-electric Cell

A, Wire from negative terminal of battery passing through a seal into the inside of the bulb and making electrical connexion with the inside coating B, Portion of bulb coated on inside with thin film of silver on which is deposited the alkali metal from which the negative electrons are emitted C, Transparent portion of bulb through which the light falls on the alkali metal D, Electrode (anode) passing up into interior of bulb and connected to positive electrode of battery.

They are little vacuum lamps, of a kind somewhat between a wireless valve and the cathode-tube I told you about in Chapter XV. You know that a cathode is the negative plate or "pole" from which a stream of electrons is sent out; and that in the thermionic valve the electrons are attracted to the plate or anode, which is positively charged. In the photo-electric cell, the cathode is a part of the tube itself, that part being thinly coated with one of the light-sensitive metals I mentioned. The anode is a little grid, or gauze, which is kept positively electrified. There is a little " window " in the cell by which light can enter.

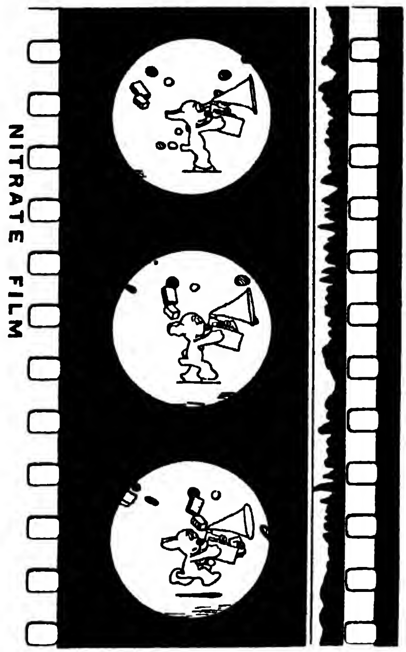
This is how the cell works. It is connected in an electric circuit in such a way that the grid receives a positive charge. Nothing happens unless light falls upon the sensitive metal forming the cathode; as soon as light enters the " window " the cathode pours out electrons, which are attracted to the grid. A minute current is then set up, so small that it is measured in millionths of an ampere, yet sufficient to control the current in the circuit, in the way wireless waves control the current passing through the valves. The stronger the light, the stronger is the stream of electrons emitted by the sensitive metal. The changes in the intensity of the light which reaches the photo-cell are thus the means of setting up corresponding changes in the strength of an electric current.

Perhaps you see how a photo-cell makes it possible to change the variations of light passing through a cinema film into the variations of current needed to work a loudspeaker. I dare say you wonder how it is possible to imprint the original sound waves on the film. How can one make a picture of sound? Remember that we are constantly translating sound into electricity; we do it whenever we use the telephone and we reverse the process when we switch on the wireless. The actors in the talkie studios create sound waves, which are received by the microphone. The vibrations in the microphone set up corresponding variations in an electric current. Now, a fluctuating current will make a source of light fluctuate in sympathy with it, and there are many ways in which this can be arranged. So, while the play is being filmed, and the actors speak their parts,[1] their voices cause the brightness of a light to vary. Mirrors concentrate this light upon a shutter in the camera which

[1] The sounds may be separately recorded, in a special studio, and the dialogue and action afterwards joined together on the film.

specially controls the "sound track" of the moving film.

This "sound track" is only $\frac{1}{10}$ of an inch wide. In one system it consists of a series of parallel lines, which have different degrees of transparency according to the amount of light—and thus of sound—which reached them. In another system the sound-track resembles the teeth of a saw. Unlike the parallel lines, which are of the same size but of different density, the saw-teeth are of the same density but of varying size and shape—like a saw that has been ill-used. It is the business of the projector to reinterpret the lines on the film, or the saw-teeth, as sound vibrations.



Portion of a Film with Sound-track at right-hand side

A part of the projector is a most beautiful apparatus, called the sound-head, placed immediately below the ordinary "gate" and lenses which project the pictures. The film passes through a "gate" in the sound-head, which exposes the sound-track to a very strong light, provided by a special lamp. The light from this lamp is concentrated by a condenser upon a narrow slit, the exact width of the sound-track. After passing through the slit, the light is focussed upon the film. The varying density of the parallel lines on the sound-

track or the varying area of the saw-teeth modifies the light so that it falls upon a photo-electric cell as a beam of fluctuating strength. The diagram on p. 250 shows, in outline, the several processes by which the fluctuating light reaching the photo-cell controls the current in an electric circuit. After several stages of amplification by valves, the fluctuations in their turn control the intensity of the vibrations of the loudspeakers. I am sure I need not add that the arrangement of the various valves, resistances, and condensers is extremely complicated. There is such a multitude of switches and controls on which the projectionist must keep watch, that the normal allowance of eyes and ears seems to be insufficient for the purpose.

A great deal of inventive skill is being concentrated on the problem of better—and simpler—talkies. It is quite likely that the existing systems will very soon be out of date and that the cinema theatres must face the introduction of entirely new principles of sound recording and reproduction. The most promising of these is based on the principle of the "singing wire" in which the sounds are printed electromagnetically on a steel wire. It is quite an old idea, but it has now been brought to a wonderful degree of perfection. It gives truer reproduction, indeed, than any other method yet discovered.

The "singing wire" has now become the "talking ribbon". It is a narrow band of very thin, flexible, stainless steel, much like that often used for tape-measures. The sounds to be recorded on the ribbon are received by a microphone in the usual way. The ribbon travels between the poles of an electromagnet, through the coils of which there passes the varying current set up by the microphone. The strength of the magnetic field consequently varies according to the frequencies of the sounds, and the moving ribbon

thus becomes a magnet of constantly changing strength. These magnetic variations in the ribbon are permanent and can very easily be turned again to sound waves, for we know how a magnet induces an electric current. The ribbon can be stored for a lifetime without losing its magnetism and wound up and rewound hundreds of times. One may imagine moving pictures photographed upon the talking ribbon, but it is less easy to imagine how they could be projected, at any rate by the methods now used.[1] However, many scientists seem to think that the talkies of the future will depend on this wonderful ribbon of stainless steel.

In whatever way they are produced, the talkies will continue to fill the cinemas for many years to come. In time, perhaps, they may have to give way to entertainments depending on television, which is the wireless transmission of actual scenes. Television depends upon the property of the photo-electric cell to change light variations into variations of electric current. So, of course, does the telegraphing of pictures, whether by wires or wireless. There are several systems in commercial operation by which reproductions of photographs and sketches, plans and such like are very successfully transmitted over long distances.

Television is quite different, inasmuch as it loads upon a wireless wave the millions of details that compose, not a picture, but living persons and scenes. I can only give here a very general outline of how it is done. In Britain, the best known of the several methods developed in recent years is that invented by Mr. John L. Baird, and I shall therefore deal particularly with this. The number of books on television is constantly increasing, and readers who wish to follow the subject more intimately will have no difficulty in finding a suitable guide.

[1] Photographs on a non-transparent material like steel could be projected by reflection.

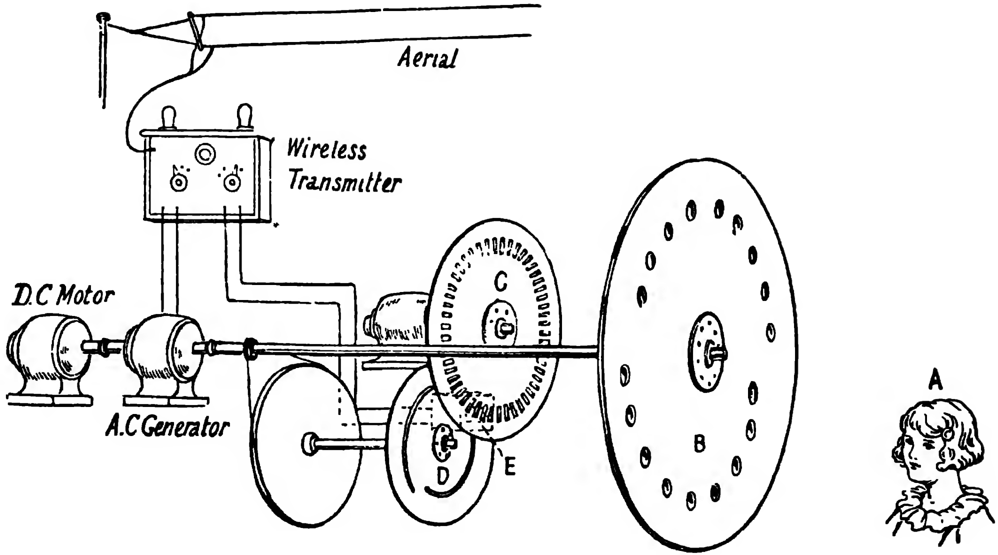


Diagram of Original Model of Baird Transmitter

A, Object to be transmitted. B, Revolving disc with lenses. C, Slotted disc revolving at high speed. D, Rotating spiral slot. E, The aperture through which the light passes to the light-sensitive cell

In every system of television the first step is to break up the subject to be transmitted into a vast number of tiny parts, somewhat like the dots into which the blockmaker's process screen breaks up a photograph, as explained in Chapter X. Each dot has a different capacity for reflecting light; the light portions will reflect most light, the half-tones will reflect less, and the dark portions least. So, if the light reflected by each part is brought to bear on a photo-electric cell, it will convey its distinctive impulse or "message" as a variation in the strength of the current controlled by the cell. These messages are used to "modulate" a wireless wave, just as though they were current variations controlled by a microphone.

Now, the light-impulses, thus converted into electric impulses, cannot be transmitted simultaneously. They must be sent, dot by dot, one after the other. A mechanical device is therefore introduced to analyse or "scan" the subject, breaking it up into dots of varying brilliancy, each of which sends its light *in turn* to the photo-electric cells. A very ingenious way of scanning the subject is used by Mr. Baird. This consists of a series of perforated discs revolving between the subject to be transmitted and the photo-electric cell. The first disc has a number of holes at unequal distances from the centre. The next has a great number of slots, and revolves much more quickly. Thus the light reflected from the subject (which must be strongly illuminated) reaches the cell in a series of very rapid flashes. A third revolving disc, having a spiral slot, still farther subdivides the image.

To reproduce the image, much the same process is carried out by the receiver. The varying current coming into the aerial causes corresponding fluctuations in a light in the receiver circuit. The beam from this light passes through rotating discs which must be kept perfectly in step

with those at the transmitter. The variations in the intensity of the beam of light fall on a little ground glass screen, where they show a reproduction of the original object or scene. The spot of light scans the screen, dot by dot, but it does it so quickly that the screen seems to present a complete image to the eye. Why? Well, what about persistence of vision?

CHAPTER XIX

Fuel of Fire

"John, John!" cried the anxious mother. "Baby is eating the coal!"

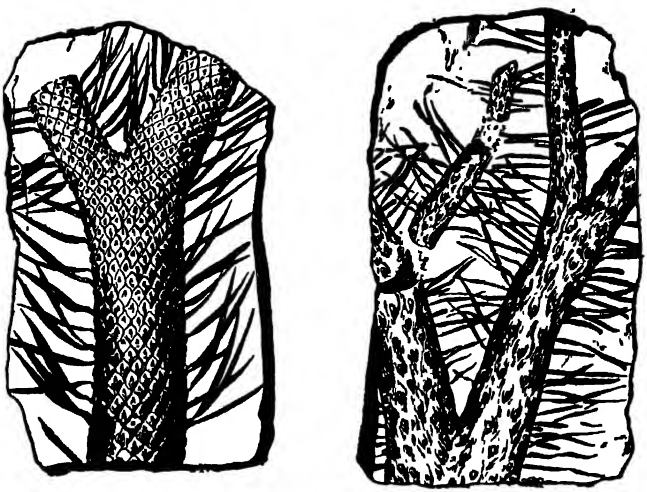
"Well, my dear," replied the practical father, "I should let him do it. After all, it is the cheapest thing he can eat."

A frivolous story with which to open a chapter in a scientific book? Perhaps so, but it is a true story. When we consider the enormously expensive business of coal-mining, and the heavy cost of transporting coal from the pit-head to the retailer's yard, and from the yard to our coal-cellars, one thing which strikes us very forcibly is the cheapness of coal. For, what else is there that we can buy at four pounds a penny?

But of course the weak point in my frivolous story is that coal, however well it may serve for feeding furnaces, is not really to be recommended as a food for babies. Nevertheless, all babies and all puppies eat coal whenever they have the chance. Ask any mother, human or canine.

You do not need to be told that coal is the product of vegetable remains laid down many geological ages ago in beds of sand and sediment. I expect you know that the

beds were compressed into hard solid rock by layer upon layer of sediment laid down above them through millions of years. But why should that rock be combustible any more than other rocks? Because in all that unthinkable space of time it has never lost the qualities of its vegetable origin. Those mighty trees of the coal age, that have no living relations to-day, except humble plants like the mare's tails and



Fossil Coal-plants. A Horse-tail on left and a Club-moss on the right

club mosses, yet were composed of the same substances as our own oaks and elms. That is to say, their structure was mainly of cellulose. Cellulose is a word we have met with before in this book, and it is a compound of our three old friends carbon, hydrogen, and oxygen. Now, when a giant sigillaria or calamite, or some other of the tremendous trees that formed the coal forests, died of old age, it just lay where it fell, gradually sinking into the oozy marshy soil. Next time the nearest river or lake was flooded with heavy rain

and overflowed its banks, a mass of sediment would be spread out all over the surrounding land. This process was repeated time after time, and each sedimentary layer helped to compress the vegetable matter into a harder mass, until at length it became veritable rock.

But in the process the cellulose lying in moist or water-logged soil gave up some of its original constituents. It gradually decomposed, and the hydrogen, allied to some of the carbon, escaped throughout the formation as a gas—marsh gas, which is one of the dangerous gases met with in coal-mines. Some of the carbon allied itself with the oxygen to make another gas—carbon dioxide, which also is dangerous. Eventually, after a period of time which we can talk about but cannot possibly realize, the cellulose is so much changed that it remains simply as a carbonaceous mass. This is the hardest coal, which is almost pure carbon. Younger coals contain more hydrogen and oxygen, and the cellulose is not so completely changed; there are more recognizable traces of its vegetable origin. Anthracite is the hardest of coals, and because it retains so little hydrogen and oxygen, it gives hardly any flame in burning, and needs a great deal of heat to start its combustion. The younger and softer coals are those we burn in open grates,[1] and younger still are brown coals and lignites, and youngest of all—peat. If we look at specimens of these various kinds of fuel, we can see how gradually the change is wrought from wood to rock.

Apart from its everyday use as fuel, coal is made to serve many purposes. The most widely known is its conversion into gas, that is to say, the coal-gas of commerce. You can easily make gas for yourself, for if you put some tiny lumps of coal in the bowl of a pipe and seal the top of the bowl with clay, and then heat the bowl, in due course gas will

[1] We only *half* burn it. See Chapter XI, p. 140.

escape through the stem of the pipe, and may be lighted with a match. But if gas-works were to be conducted on such simple lines, the gas would be dirty—it would burn with a dull flame and a much worse smell than the one most of us are acquainted with. Moreover, the gas would be terribly expensive. The fact is that gas-works are very busy producing many things besides gas, and the side lines are as valuable as the main product.

In the first place the coal is heated in a retort until the gas, together with other substances, is given off. The gas travels away from the retort through water-cooled pipes, and the residue left in the retort is coke. When the gas is cooled it enters a "washer", where it passes through water in which it leaves ammonia. And it also leaves another very important product, tar. Two more purifying processes free the gas of sulphuretted hydrogen and carbonic acid gas, and it is then ready to be pumped into the big circular gas holders which disfigure every town—as some of us think—and to be pumped again into the mains supplying streets and houses.

The ammoniacal liquor which was washed out of the gas is sent to a chemical works to be dealt with, for the wizard of the laboratory can transmute it into many useful things. First of all he takes from it *sal ammoniac* (ammonium chloride), which works the battery which rings the bells in nearly every house. Then he makes *ammonium sulphate*, used by farmers and gardeners for fertilizing the soil. The ordinary liquid ammonia seen in most households is also of importance in various trades.

The tar deposited by the gas is even more wonderful than the ammonia. In the eighteenth century the ninth Earl of Dundonald obtained a patent for extracting tar from coal for the sole purpose of pitching ships' bottoms. The tar

distilled at the gas-works to-day still contains pitch, used in huge quantities for road-making as well as for water-proofing. It also contains a green oil, the basis of wonderful colours in dyestuffs, and crude naphtha from which come more dyestuffs, waterproofing oils, a material used in making celluloid, benzol, and benzoline. Another very valuable product of tar is carbolic acid, which everyone knows as a disinfectant, and from which such diverse things as explosives, many drugs, scents, and still more dyestuffs are derived. Yet another product of tar is creosote oil, also well known for its disinfectant qualities—as a preservative for wood, for spraying fruit-trees to cleanse them of insects, and as a sheep dip.

Coal-gas has been in common use for lighting purposes for nearly a hundred years, but how were houses lighted before the methods of extracting gas and carrying it under ground were discovered? Well, we may say that they were lighted by fat, or preparations of fat. Animal fat, fish fat, vegetable fat—all were in use either in a liquid form in lamps or in a solid form as candles. Mutton fat, or tallow; wax; spermaceti from the sperm whale; all made candles. Whale and seal oil, or colza oil, which is obtained from the seeds of rape, a plant of the cabbage tribe, were burnt in lamps. Oil, that is mineral oil or petroleum, was found in the East and had been in use there for thousands of years, but it was difficult to transport. Oil is so utterly out of date as a general illuminant now that it is something of a shock to find that the paraffin industry is really quite a modern one; for though various attempts had been made to obtain mineral oil profitably, nothing successful on a commercial scale was achieved until 1850, when a native of Glasgow, named James Young, took out a patent for extracting paraffin oil by the distillation of soft coal—" cannel coal " as it was called because it burnt like a candle. At a place

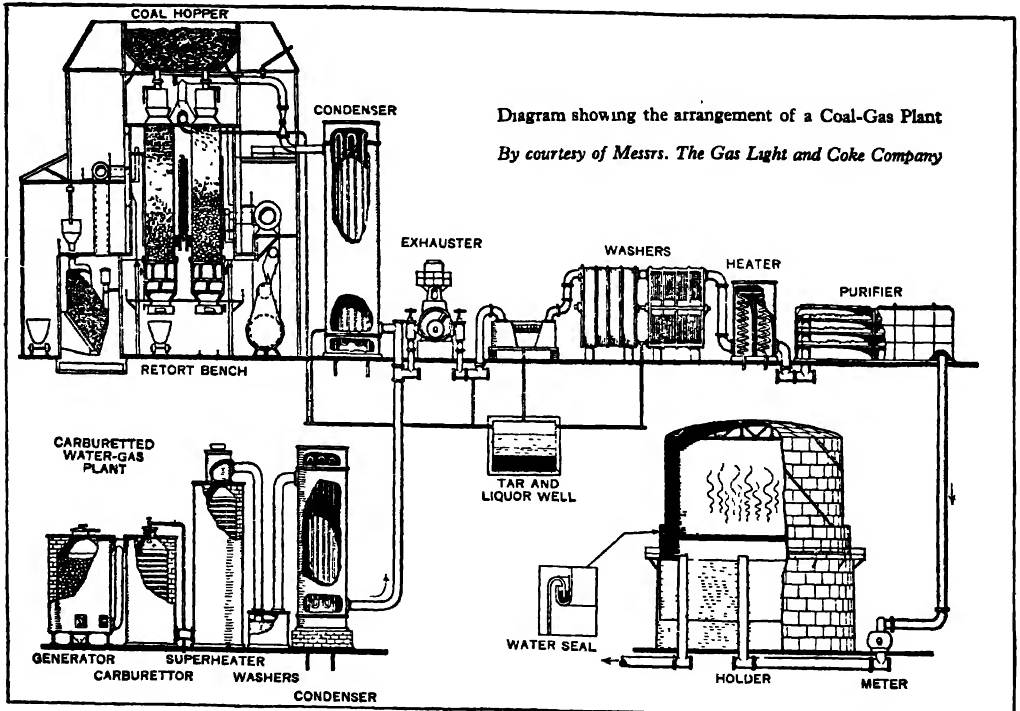


Diagram showing the arrangement of a Coal-Gas Plant

By courtesy of Messrs. The Gas Light and Coke Company

called Boghead in Scotland there were rich deposits of this kind of coal, and there Young set up his works. This particular kind of oil, called shale oil, gives a very fine clear light, and there has never been a better oil on the market for lighting purposes than Scottish shale oil.

There is much more doubt in the minds of geologists as to the origin of petroleum than there is about the origin of coal. Some think it is an entirely inorganic product, a theory which is supported by the fact that in Canada oil wells exist in the old geological formation called the Devonian, in which there is very little trace of organic matter. But other geologists believe that mineral oil is a result of the decomposition of vegetable and animal matter, as it might be when found in the more recent geological formations in which it exists in the United States and in Persia and the Caspian districts. These countries of Western Asia have been the scene of vast developments on account of their oil wells. You have heard of the pipe-lines through which the oil is pumped from the oil-fields to seaports hundreds and even thousands of miles away. There is now going forward a gigantic international scheme for bringing oil from a very rich oil-field near Mosul, in northern Iraq, to ports in Palestine and Syria, on the eastern shore of the Mediterranean. This involves laying heavy steel pipes over a distance of nearly 1200 miles, a great part of which lies in rocky and waterless desert. Each pipe weighs nearly a ton and they have to be transported over the roadless desert by motor tractors, then laid in trenches dug by mechanical excavators or blasted by dynamite. The pipes are welded together, and finally covered in.

Even while this great work is being carried out, to add more millions of tons of oil to the 200,000,000 tons already used each year, huge factories are going up in South Wales

for turning coal into oil. You need no reminding of the extent to which the world has become dependent on liquid fuel. Almost every land is bespattered with petrol pumps, but they only show us one aspect of our dependence on what we may call fossil-wealth; the minerals we convert into the heat-energy of fire. The power of steam, both in ships and on land, is largely obtained by burning oil. And Diesel engines, in which a heavy oil is ignited by the heat arising from compression instead of an electric spark, are very formidable rivals of steam and petrol. They drive ships and factories, electricity works, buses, lorries, and railway trains, and before long, no doubt, they will be driving aeroplanes.

This heavy oil, or fuel oil, is the residue left in the retorts used at the refineries for distilling the oil into its many different compounds of carbon and hydrogen. These compounds or " fractions " are driven off as gases at different temperatures, and the process is consequently known as fractional distillation. At the lowest temperature, naphtha and petrol are driven off, and then condensed. Most of our petrol, however, is made by a process called " cracking ". By heating the oil in vessels at a tremendous pressure, the petrol is set free by a chemical agent of a kind called a catalyst.[1] A catalyst brings about a sudden decomposition of a compound and causes an immediate rearrangement of the atoms in new ways.

And now petrol and lubricating oils and fuel oil are being made out of coal. This is called hydrogenation, because it depends on forcing hydrogen to combine with the carbon in the coal, to bring about the necessary change. The process is one of the most splendid and sensational achievements of science, of a complexity beyond the reach

[1] From Greek words meaning " to loosen ".

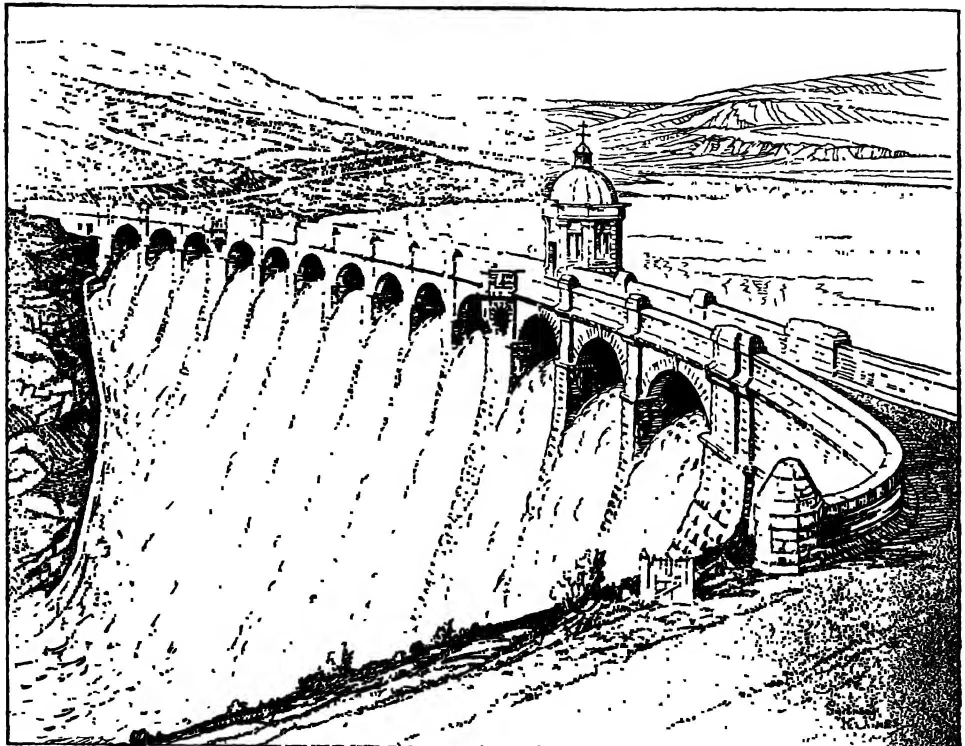
of most of us unless and until we take the trouble to learn chemistry. In a few years' time, probably, when the new factories are functioning, we may look upon hydrogenation as a matter of *everyday* science. And it opens up for us a new vista of the chemist's power, a splendid vista of the promised marvels of the science of to-morrow.

CHAPTER XX

Water at Work

Of water we say, as we say of fire, that it is a good servant but a bad master. Indeed, it would be hard to find a more patient, hard-working servant than the stream of water which flows on, day and night, turning the mill-wheel or working the ram; requiring nothing in the way of food or fuel but winning all its support from the never-failing hills. But not even fire is crueller or more devastating than water in its ravages. Fire can be subdued by science and dauntless effort; water which has gained the mastery sweeps unhindered over the land and nothing can stay it. Yet the two taking service together have produced modern civilization, since by their union man obtains his servant, steam.

Water being a vital need of life, it is not surprising to find that all the great civilizations of the world have arisen beside great rivers. But modern society calls for such vast supplies of water that the problem of meeting the demand becomes more and more difficult to solve. During the last fifty years or so many towns have found their parent streams sadly insufficient for their needs, not, as you might suppose, merely because the towns have grown in population, but



Craig Gôch Dam and Reservoir which supplies Birmingham with water.

chiefly because everyone wants more water than sufficed for his father. We use much more for domestic purposes, and industries also use much more, and our water engineers are often sadly perplexed to know where it is to come from. People who live in towns use on an average more than thirty gallons a head a day.

I tried to show you, in Chapter IV, how difficult it is to comprehend big figures. It sometimes helps us to clearer ideas of the meaning of numbers if we approach them through things that we can easily picture. We might take the town-dweller's daily thirty gallons. Suppose there are a hundred residents in your street, then their share of the town's water supply is 3000 gallons. You can see what a tiny drop that is in a town's bucket. You can easily work out for yourself the size of *your* town's bucket. I will give you an idea of the size of London's bucket. I expect you have seen Nelson's Column, in Trafalgar Square. The square has an area of two and a half acres and the column is 142 feet high. If you made a tank twice that area and 140 feet deep, it would not contain enough water to supply London's needs for twenty-four hours.

Birmingham affords a good example of a town which outgrew its strength in the matter of its water supply. Birmingham grew so fast that it trebled its population in eighty years, and in the second half of the nineteenth century it became evident to the city fathers that something must be done. The two streams Rea and Tame on which the city stands no longer sufficed for the vast industry carried on by the quarter of a million inhabitants, but where could more be obtained? You may not tap your neighbour's water supply, any more than you may move his landmark, and a glance at a map will show you that Birmingham is surrounded by other towns, far from any considerable range

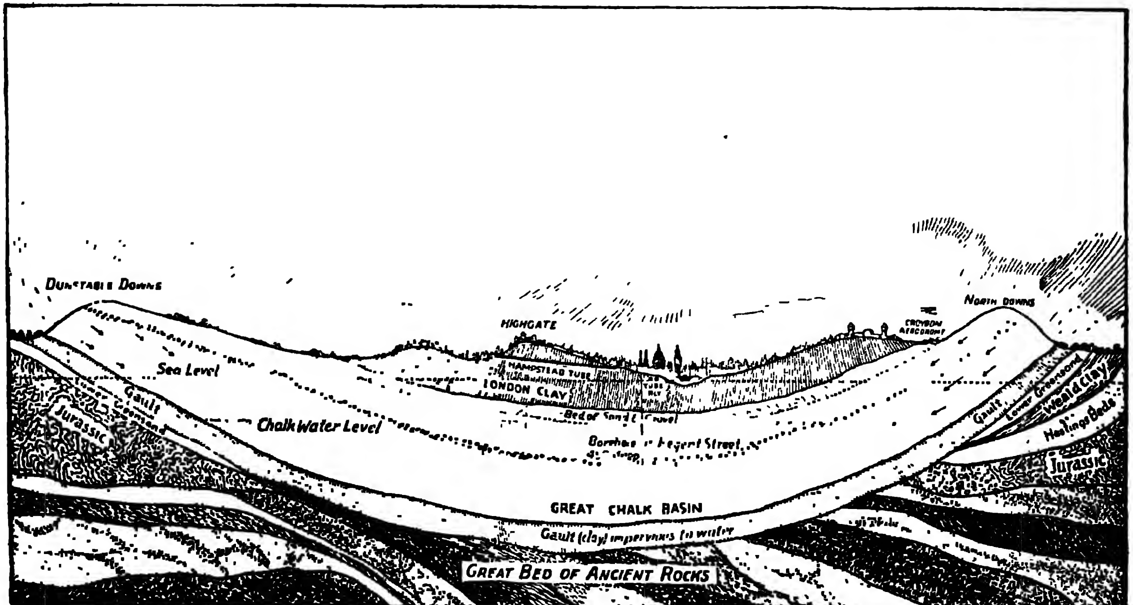
of hills or a river of great size. In the end, the engineers entrusted with the work of providing the city with an unfailing water supply totalling many millions of gallons a day took their theodolites and boring tools right across Worcester, Shropshire and Hereford into the Welsh county of Radnor, where, in the valley of the river Elan, they found what they were looking for. The Elan drains a great horseshoe of mountains, and at the narrowest part of the horseshoe the engineers built a series of three dams, thus turning the valleys into a great chain of lakes some 1500 acres in extent. A similar scheme has been carried out by Liverpool in damming the valley of the River Vyrnwy in Montgomeryshire, thus forming a huge natural reservoir. Undertakings of such a kind have involved the spending of large sums of money in building the dams and in laying down the seventy or eighty miles of pipe required, and it may be said: " Surely they need not have gone so far!" But apart from the questions of constancy and quantity already referred to, there is a third point which is of great importance to a municipal water supply. That is the question of the height of the source. As everyone knows, water will return by its own energy to a height equal to that from which it started, and as the chosen valleys are high above sea-level, the cities which they serve receive water which has a considerable force behind it.

London is in a very favourable position as regards water supply. The city rests upon a geological formation known as London clay, which is impermeable to water. But beneath the clay lies a bed of grey sand, and beneath that again a bed of chalk and flints, six to seven hundred feet thick, in which are stored boundless quantities of pure water. Wells sunk into this layer of chalk provide one-fifth of London's water supply, the remainder being drawn

principally from the Thames and the Lea. If you live in or about London it may seem to you that the water of its rivers cannot be very nice to drink. But it is not really as bad as it looks. Very elaborate precautions are taken against pollution, though for that matter even polluted water can be cleansed. All water contains traces of the gases of the atmosphere, and minerals dissolved out of the rocks through which it has passed. It is also the home of many sorts of microscopic plants and animals and—until it is filtered—it is full of their dead remains.

Another form of water supply is that which is obtained direct from springs. Water which falls upon the surface in the form of rain trickles away through the subsoil until it reaches an impervious layer—a layer of rock, like clay, through which it cannot penetrate—when it must run along until it finds an outlet. The crust of the earth is by no means solid. Cavities frequently occur, as for instance, between fractured and distorted layers of rock, and in certain geological formations such as limestone and chalk, there may be quite large underground chambers in which water may collect. In rural districts the well is the usual source of supply, either a deep well from which the water must be brought up in a bucket, or a surface well or " draw-hole " from which it can be pumped. Or the water may come to the surface of its own accord, without pumping, from an *artesian* well. The name is derived from the province of Artois, in France, where such wells have been in use for centuries.

The point about an artesian well is that the well-shaft is sunk right down into a water-bearing layer *beneath* an impervious layer. The water-bearing layer may be fed with water coming down from ground at a much higher level—perhaps from a range of hills miles away. Consequently



Section through the London Basin. To the north-west of London the chalk appears at the surface as the Chiltern Hills (of which the eastern spurs are called the Dunstable Downs), then it makes a long sweep underground, reappearing on the south-east side of London to form the hills of the North Downs. This bed of chalk is about 700 feet thick and rests on impermeable rocks, but the chalk itself is porous and the rock acts like a gigantic reservoir from which London is able to draw a great part of its water.

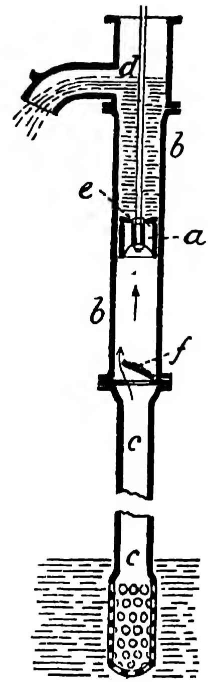
the water in artesian wells has a force behind it that can push it to the surface, and possibly much higher than the surface.

The wells of London of which mention has already been made are artesian wells sunk into the water-bearing chalk beneath the clay. When the water is raised it is carried in pipes to reservoirs. Water raised from far below the surface has to be stored in covered reservoirs, as on exposure to the light it may become covered with a green scum, so when you see open-air reservoirs you may be sure that they are supplied by spring or river water. At Honor Oak, a few miles south-east of London, is one of the largest covered reservoirs in the world. It has an area of ten acres, and anyone standing in it before the water was let in might have fancied himself standing in the crypt of some vast cathedral, for the roof is supported on pillars and arches.

From its first reservoir, where it stays long enough to allow the impurities to settle, water is pumped into other reservoirs or filtration beds. The filtering is performed by layers of sand and gravel superimposed on a layer of pipes, and the filters have to be cleansed after every three or four weeks' use. The water is now ready for consumption. London, as we know, has its water "on the spot", and it can be led direct from the filtration beds to the great valve chambers which regulate its flow.

You may have noticed as a curious thing about your imagination, that it is least excited about the commonest objects. Water is such a very commonplace thing that it does not interest us much. Yet for that very reason I am sure you can see that water-science must really be a very important branch of everyday science. It is also an extremely complicated branch. I have told you a little about water supply because that is a matter of vital concern to us

all. But the ship-designer and the dock or harbour engineer are interested in water from quite another point of view; so are the chemist, the geologist, the meteorologist, and goodness knows how many more logists. So, too, is the hydro-electric engineer, whose business it is to convert the stored up energy in water that has been raised by the sun above sea-level, into electrical energy. All mountainous countries possess in their lakes and waterfalls reserves of power that are being turned to good account. The power of water to do work is dealt with by a branch of science called hydro-dynamics, and the machinery by which the work is performed is called hydraulic machinery.



Section of a Suction Pump

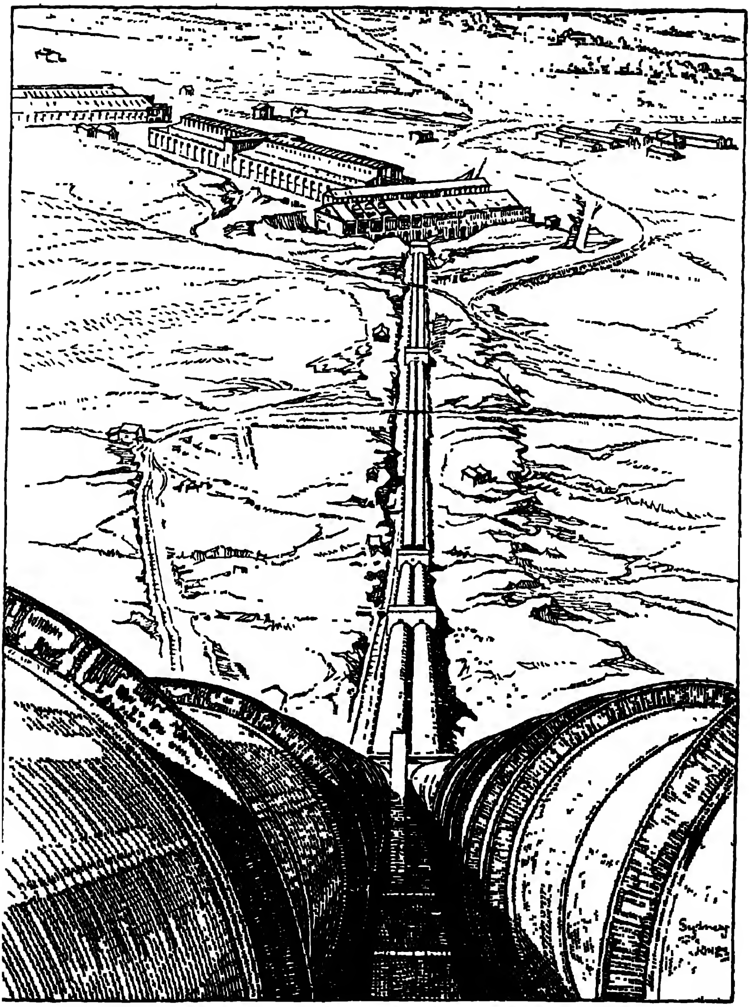
A piston *a* is fitted to work within a hollow cylinder *bb*, it is provided with a valve *e*, opening upwards. At the bottom of the barrel is another valve *f*, also opening upwards and which covers the orifice of the tube *cc*. When the piston is drawn up the air below is rarefied and the pressure of the external air on the surface of the water causes the water to rise in the tube. After a few strokes the water will get into the barrel, the air below the piston having escaped through the piston valve *e*. By continuing the strokes the water will get above the piston and be raised to *d* where it will be discharged by the spout.

The only hydraulic machine with which most of us have anything to do, however, is that very simple contrivance the common pump. We looked at the air-pump on p. 154. Let us now see how we can make the weight of the atmosphere bring the water out of the well.

In its simplest form, the lift or suction pump comprises a barrel or cylinder of metal from which runs a suction pipe down to the water to be raised. The barrel is provided with

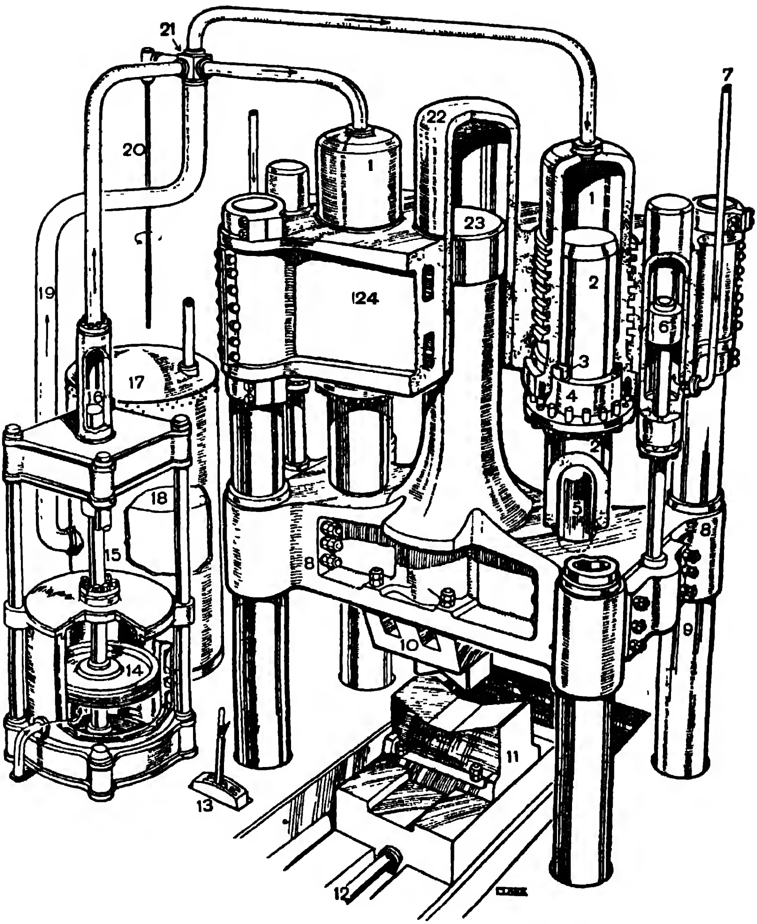
a spout for the outflow of water. Within the barrel is a piston-rod or plunger worked up and down by a handle. In the base of the plunger, which is packed up to fit the barrel exactly, there is a valve opening upwards only, and there is another similar valve at the head of the suction pipe. When the piston-rod with its valve is drawn upwards, it pushes the air above the valve out of the spout, and the air below the valve is at the same time drawn upwards (provided the valve itself is air-tight), opening by suction the lower or fixed valve in order to allow the air to come from the top of the suction pipe into the pump barrel. This suction causes a partial vacuum in the pump barrel and the pipe, so that the pressure in them is less than the atmospheric pressure. As the pressure at the surface of the reservoir is ordinary atmospheric pressure, the water rises a little in the pipe, and so reduces the intensity of the vacuum.

The next step is to push the piston downwards. This at once closes the lower valve so that no air can escape down to the pipe. As the piston descends the air between the two valves begins to be compressed and this pressure opens the upper valve as it is pushed downwards and lets the compressed air through, so that it occupies a position *above* the upper valve instead of below it. The upper valve has now arrived at the bottom of the stroke. Remembering that the state of affairs below the lower valve is as it was when we started the downward stroke, we will now start the piston on its next upward journey. The air above the upper valve is again pushed out of the spout, and again the air below it is drawn upwards, and the water drawn after it a little farther up the pipe. We continue to work the piston up and down, and we soon find that all the air has been sucked up out of the pipe and its place taken by water. At each upward stroke the water above the piston



HOW SCIENCE HAS HARNESSED WATER-POWER TO MAKE ELECTRICITY

Here are seen the huge steel pipes which carry the water to the turbines driving the generators in the power-house.



A MODERN HYDRAULIC PRESS SHOWN PARTLY IN SECTION

1. The two main hydraulic cylinders. 2. Hydraulic ram.

3. " U " gland leather. (Tends to open out and press on ram when pressure water leaks down in its effort to get out.)

4. Gland ring, tightened up by studs, to take up wear on leather and allow it to be placed in its housing, &c.

5. Loose fitting bolster inside ram. (The ram doesn't bear on crosshead (8), but the pressure is transmitted through bolster, which, having spherical ends, transmits the pressure evenly, when crosshead gets slightly out of alignment. Thus no side strains may come on the ram. Bottom end of bolster fits spherically in crosshead.

6 Hydraulic piston for raising crosshead after forging.

valve pours out of the spout and the water below is drawn through the lower valve and into the pump barrel, and at each downward stroke the lower valve closes, and water is pressed through the piston valve ready to be pushed out of the spout by the next upward stroke.

We have seen that the water rises in the pipe by means of the sucking action of the pump. The more the water is raised above its natural level, which is that of the surface of the supply reservoir, the harder the pump will have to suck. We have the atmospheric pressure of 14½ lb. to the square inch on the surface of the reservoir. By removing *all* atmospheric pressure by means of the pump, we could draw the water up the pipe to a height of about 33 feet above the reservoir level, but it would come no farther. The weight of a column of water 1 square inch in sec-

---

7. High-pressure water enters through pipe to underside of piston and forces it up, thus raising crosshead.

8. Steel crosshead, pushed down by rams (2) (2) (5) (5) and guided by support-stanchions (9).

9. Main column (stanchion), one of four on which crosshead (8) slides.

10. Tool holder. 11. Anvil.

12. Hydraulic ram for moving anvil (and job) out and in. 13. One-lever control.

14. Piston in cylinder. Steam enters under it and pushes it up, thereby causing its rod (15) whose end is a hydraulic ram in cylinder (16) to rise and so push very high-pressure water up pipe, through valve (21), to hydraulic cylinder (1) The complete thing (steam cylinder, hydraulic cylinder) is called the steam-hydraulic intensifier.

17. Prefiller. Water at the bottom end of tank is blown down and out through pipe (19) by compressed air from (18) at about 60 lb sq. in., through valve (21) to the hydraulic cylinders (1).

20. Control rod to valve (21). 22. Guide cylinder, fitted in head (23).

23 The steel crosshead (8) has a long extension (stalk) which slides up and down in cylinder 22. This keeps crosshead (8) in line and prevents tilting of (8) when forging. The bolsters (5) neutralize any slight tilting which may occur from harming rams (2)

Operation: Crosshead (8) is at top of stroke. The work is put on anvil (11). Valve (21) admits low-pressure water from (17) to fill cylinders (2) which push down crosshead (8) until it touches work. The pressure is not sufficient to do forging, however. Now, valve (21) closes l.p supply from (17) and opens high-pressure supply from steam-hydraulic intensifier where steam (180 lb./sq in) pushes up piston (14) and forces water out of cylinder (16) at immense pressure through to the filled cylinders (1) thereby exerting forging pressure on rams (2) of (say) 3000 tons on each.

After the blow on the work, valve (21) cuts off pressure and water pressure is sent down (7) to underside of (6), thereby raising crosshead for next blow of h.p. water from (14), the l.p. from (17) being cut off All operations are carried out by one lever (13) and 40 odd blows can be delivered per minute if required.

tional area and 33 feet high is $14\frac{1}{2}$ lb., and as this is the atmospheric pressure per square inch, this is the limit to which water can be raised by suction. In actual practice 25 feet is the limit of an ordinary suction pump. If we want to raise the water by more than that height, we must do away with the spout of our pump and replace it with a pipe running upwards. When the piston is raised the water above the piston valve has got to go somewhere, and the only place possible is up the pipe, the piston valve being forced shut when it is drawn upwards. This form of pump is known as a force-pump, and water can be raised by it to great heights, but the pump itself must not be more than 25 feet above the reservoir.

There is one very important property of water, which makes it exceedingly useful as a means of transmitting power. It is very nearly incompressible, and pressure applied to any part of a body of water is transmitted equally throughout its mass. This means that you can increase the pressure in a vessel, by pumping more water into it, and convey it by pipes where you wish at undiminished pressure. Not many years ago water was a very important source of power, applied to machines of many different kinds. It still works lifts, cranes and presses, heavy dock gates, swing-bridges, and such-like appliances that need immense power to move them, but except for such uses it has had to give way to electricity. The hydraulic press is the most powerful contrivance in man's service, its power depending only on the strength of the materials used in its construction. An hydraulic press capable of giving a squeeze of 4 tons to the square inch can be found in any steel works, while in the largest works there are machines that apply to great forgings a total pressure of 12,000 tons, and even more.

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